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Review Article

Evaluation of Medical Image Registration Techniques Based on Nature and Domain of the Transformation

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ABSTRACT

A lot of research has been done during the past 20 years in the area of medical image registration for obtaining detailed, important, and complementary information from two or more images and aligning them into a single, more informative image. Nature of the transformation and domain of the transformation are two important medical image registration techniques that deal with characters of objects (motions) in images. This article presents a detailed survey of the registration techniques that belong to both categories with detailed elaboration on their features, issues, and challenges. An investigation estimating similarity and dissimilarity measures and performance evaluation is the main objective of this work. This article also provides reference knowledge in a compact form for researchers and clinicians looking for the proper registration technique for a particular application.

RÉSUMÉ

De nombreuses recherches ont été faites au cours des 20 dernières années dans le domaine de la superposition des images médicales afin d'obtenir des données détaillées, importantes et complémentaires à partir de la combinaison de deux images ou plus en une seule image contenant davantage d'information. La nature et le domaine de la transformation sont les deux catégories importantes de techniques de superposition des images médicales qui traitent du caractère des objets (mouvements) dans les images. Cet article présente un examen détaillé des techniques de superposition appartenant aux deux catégories, avec une discussion approfondie de des caractéristiques, des enjeux et des défis propres à chacune. Une étude détaillée mettant l'accent sur l'estimation des mesures de similarité et de dissimilarité et sur l'évaluation du rendement constitue l'objectif principal de ce travail. L'article présente également des connaissances de référence sous une forme compacte pour les chercheurs et les cliniciens à la recherche d'une technique de superposition pour une application particulière.

Keywords: Medical image registration; rigid registration; affine registration; projective registration; curved registration; local registration; global registration

Introduction

The availability of important and usable information in the field of image processing and computer vision is always required for human and machine perception. Many developments have occurred in the last few decades and, as a result, the research in these fields has reached a mature stage. Image registration, an important area of image processing, aims to geometrically align two or more images obtained in the same, or different, time frame and angle or from the same, or multiple, data sources such as computed tomography (CT), magnetic resonance imaging (MRI), single-photon-emission CT (SPECT), and positron emission tomography (PET) [1]. The purpose of image registration is to determine the necessary and corresponding points more precisely by comparing, analyzing, and transforming images obtained from different scanners (or from the same scanner) in different time frames and angles [2–6]. Figure 1 [7] shows the determination and transformation of the corresponding points in an MRI image (left) and a PET scan (right) of the same patient. After determination of the corresponding points in the input images, also called the source and target images, these are aligned by means of geometric transformations, which translate, rotate, scale, and shear the images and set them into a common coordinate system.

Besides its importance and widespread use in remote sensing applications such as change detection, integrating information into geographic information systems (GIS), and weather

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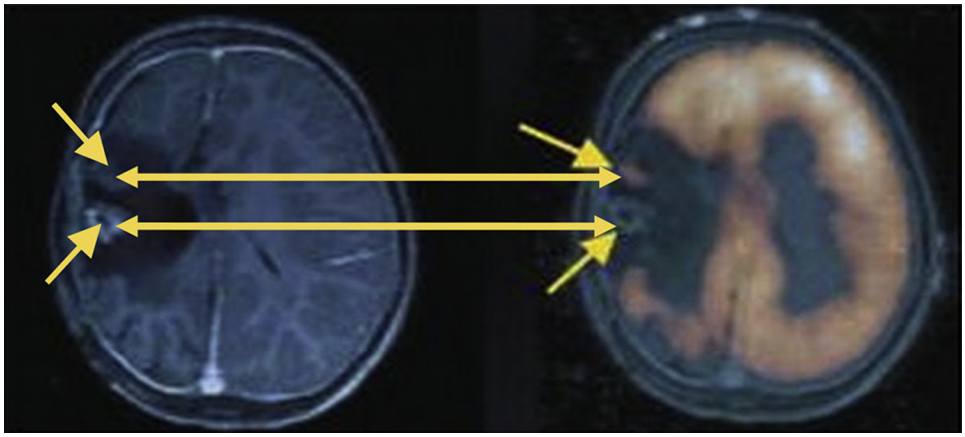

Figure 1. Determination and alignment of corresponding points in image registration. Tumor regions are identified by short arrows in MRI image (left) and in PET image (right). MRI image exhibit a low-intensity lesion while PET image show more clear identification of the lesion in that area. After the registration, a transformation is performed as shown by the long arrows. MRI, magnetic resonance imaging; PET, positron emission tomography.

forecasting, image registration also plays an important role in medical image processing. In medical image analysis, the main goal of registration is to combine useful information from various imaging modalities such as MRI, CT, SPECT, and PET [8]. Each imaging modality has its own characteristics; for example, PET and SPECT are mostly used for showing functional behavior of organs, whereas CT and MRI show anatomic contents. The common task performed by image registration in the medical field includes intrapatient registration, interpatient registration, and alignment of preoperative images to the physical reality of the patient [8]. In intrapatient registration, images of the same patient are registered over an interval. The interval ranges from a few seconds to several months, during which changes in organ size, shape, and position are monitored. Registration of medical images with different patients in the atlas is called intersubject registration. In this type of registration, an individual's anatomy is compared with other patients, or to a standardized atlas. Similarly, aligning preoperative images and surgical plans to the physical reality of the patient in the operating room during image-guided surgery is also performed with image registration.

The extraction and comparison of useful information from a set of images are performed by manual, semiautomatic and/or interactive, or automatic approaches of registration. These approaches use four major steps to perform registration; feature detection, feature matching, transform model estimation, and image resampling and transformation [8–13]. Despite advancement in image registration techniques, each step has its own problems in mapping two or more images. The implementation problems in the feature detection step include the selection of appropriate features for the given task, frequent spreading of features over the image, and their easy detection. Moreover, the detected features in two images must have enough common elements. Common problems in the feature matching step are the incorrect detection of features and the high possibility of image degradation. Therefore, it is necessary to choose feature descriptor and similarity measures carefully in the registration process. Adjustment of mapping functions according to expected image degradation and choice of precise resampling and transformation methods are problems that frequently occur at the end of the registration process. Therefore, mapping function should be flexible and must be chosen based on prior information about image degradation. Similarly, the choice of a suitable type of resampling method based on the accuracy of interpolation and computational complexity is also important for accurate registration of medical images.

Image registration techniques are categorized into several groups; among them, registration based on the nature and domain of the transformation are the most popular. Techniques based on the nature of transformation are rigid, affine, curved, and projective, whereas local and global registration belongs to domain of the transformation category. The categories that belong to the nature of transformation use different types of geometric transformation mechanisms to map points from space A of one view to space B of another view [14–16]. All the techniques belonging to the nature of the transformation provide an enormous area of analysis to resolve complex registration problems. On the other hand, domain of the transformation registration techniques—that is, local and global—require local and global transformation and computations on the set of matched points, respectively [17–21]. Registration with global techniques is generally performed in a single transformation step, whereas local techniques require multiple transformation steps. Registration based on domain of the transformation is performed using regions of an image under consideration.

In summary, the aims of this review article are the following:

- To investigate the performance of medical image registration techniques based on the nature and domain of the