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Various Methods for Medical Image Registration

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Abstract— Computerized Image Registration approaches can offer automatic and accurate image alignments without extensive user involvement and provide tools for visualizing combined images. The aim of this survey is to present a review of publications related to Medical Image Registration. This paper paints a comprehensive picture of image registration methods and their applications. This paper is an introduction for those new to the field, an overview for those working in the field and a reference for those searching for literature on a specific application. Methods are classified according to the different aspects of Medical Image Registration.

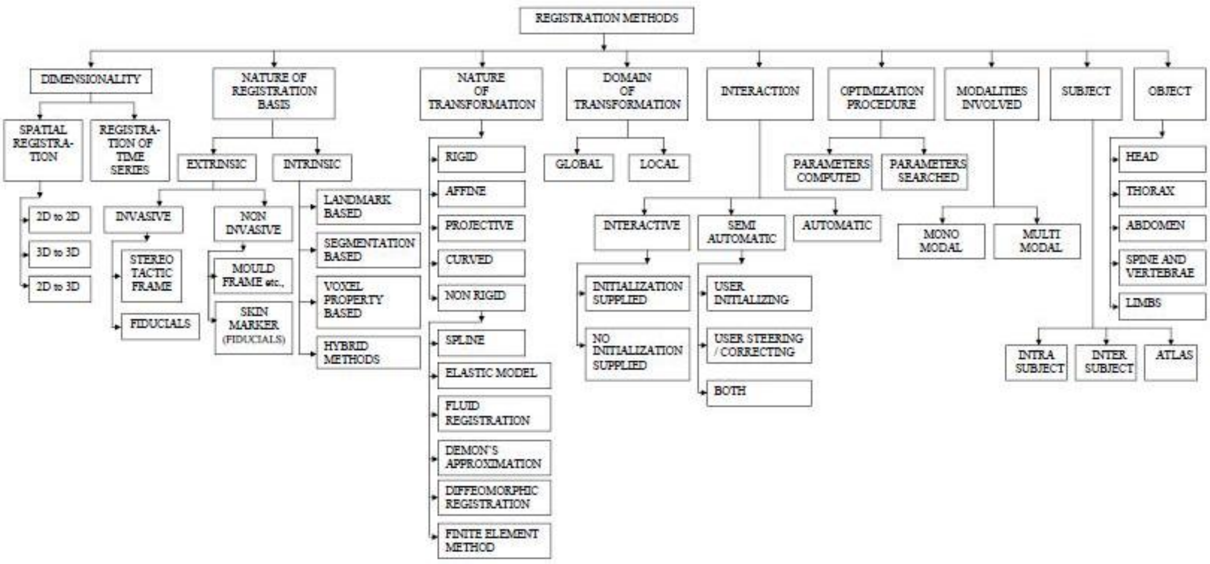
Keywords— image registration, deformable model, multimodal, extrinsic, elastic, rigid; non rigid, voxel based, feature based.

I. INTRODUCTION

This Image Registration is an important pre-processing stepin Medical image analysis. Medical images are used for diagnosis, treatment planning, disease monitoring and image guided surgery and are acquired using a variety of imaging modalities like Computer Tomography (CT), X-ray, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Ultrasound, etc. So images obtained using different modalities need to be compared to one another and/or combined for analysis and decision making. To monitor disease progress and growth of abnormal structures, images are acquired from subjects at different times or with different imaging modalities. Misalignment between images is inevitable and this reduces the accuracy of further analysis Image registration is a task to reliably estimate the geometric transformation such that two images can be precisely aligned. Any registration technique can be described by three components: a transformation which relates the target and source images, a similarity measure which measures the similarity between target and source image, and an optimization which determines the optimal transformation parameters as a function of the similarity measure. Image Registration plays an important role in medical image analysis, group analysis and statistical parametric mapping. Because of its importance in both research and medical applications, Medical Image Registration has been intensively investigated for almost three decades and numerous algorithms have been proposed. Much of the early work in medical image registration was in registering brain images of the same subject acquired with different modalities (e.g. MRI and CT or PET) . For these applications a rigid change in brain shape or position within the skull over the relatively short periods between scans. Today rigid registration is often extended to include affine registration

II. CLASSIFICATION OF REGISTRATION METHODS

The registration methods can be classified based on the criteria formulated by Vanden Elsen, Pol and Viergever . Nine basic criteria are used, each of which is again subdivided on one or two levels. The nine criteria and primary subdivisions are: represented in the following tree diagram.



III. DIMENSIONALITY

1. Spatial Dimensions The process of registration involves computation of a transformation between the coordinate systems of the images or between an image and physical space

2. 3D-to-3D Accurate registration of multiple 3D MR and CT volumes is the most common and fully developed method. The spatial relationship between the internal organs of the patient has not distorted or changed and the imaged organ behaves as a "rigid body." In 3D Rigid registration three translations and three rotations are sufficient to bring the images into accurate alignment. The scanning devices must be calibrated to determine image scaling, i.e., the size of the voxels in each modality must be known. 3D/3D registration is used to accurately register tomographic datasets, or to register a single tomography image to any spatially defined information.

3. 2D-to-3D 2D-to-3D registration is used for establishing correspondence between 3D volumes and projection images like x-ray. 2D-to-3D registration is done when the position of one or more 2D slices are to be established relative to a 3D volume. The main application of these methods is in image-guided surgery. Hence their computational complexity must be reduced without affecting the accuracy. Diagnostic applications outside the Operation Theater and radiotherapy setting allow for off-line registration, and here computational complexity and speed is not an issue.

IV. NATURE OF REGISTRATION BASIS

All Medical Image registration can be divided into Extrinsic method i.e., based on foreign objects introduced into the imaged space, and Intrinsic methods, i.e., based on the image information generated by the patient himself.

4.1. Extrinsic Registration Methods

In Extrinsic registration, artificial objects are attached to the patient and they must be clearly visible and accurately detectable in all the modalities. These registration methods are computationally efficient and can be automated easily. They do not require complex optimization algorithms, since the transformation parameters are computed easily. The following external markers are commonly used in medical imaging.

- Stereo tactic frame screwed rigidly to the patient's outer skull
- Screw-mounted markers
- Markers glued to the skin

Extrinsic methods does not include patient related image information, the nature of the registration transformation is often restricted to be rigid (translations and rotations only). If these methods are to be used with images of low (spatial) information content such as EEG or MEG, a calibrated video image or spatial measurements are often necessary to provide spatial information for basing the registration. Because of the rigid-transformation constraint, and various practical considerations, use of extrinsic 3D/3D methods is largely limited to brain and orthopedic imaging, although markers can often be used in projective (2D) imaging of any body area . Non-rigid transformations can in some cases be obtained using markers, e.g., in studies of animal heart motion, where markers can be implanted into the cardiac wall

4.2. Intrinsic Registration Methods

In Intrinsic registration methods salient visible Landmarks, segmented binary structures, or voxel intensities of the image are used as reference

4.2.1. Landmark Based Registration Methods

Landmark based approaches use identifiable prominent anatomical elements in each image. These elements typically include functionally important surfaces, curves and point landmarks that can be matched with their counterparts in the second image. Anatomical landmarks used were sparsely distributed throughout the images. These correspondences define the transformation from one image to the other. The use of such structural information ensures that the mapping has biological validity and allows the transformation to be interpreted in terms of the underlying anatomy or physiology. Corresponding point landmarks can be used for registration provided landmarks can be reliably identified in both images. Landmarks can either be defined anatomically or geometrically by analysing how voxel intensity varies across an image. When landmarks are identified manually, it is important to incorporate measures of location accuracy into the registration .After establishing explicit correspondences between the pairs of point landmarks, interpolation is used to infer correspondence throughout the rest of the image volume in a way consistent with the matched landmarks

V. NATURE OF THE TRANSFORMATION

5.1. Rigid

Translations and rotations suffice to register images of rigid objects. Examples include registration of bone or of the brain when neither skull nor dura has been opened. .Rigid registration is also used to approximately align images that show small changes in object shape (for example, successive histological sections and serial MR images) or small changes in object intensity, as in functional MR time series images. The global rigid transformation is used most frequently in registration applications. It is popular because in many common medical images the rigid body constraint leads to a good approximation. Furthermore, it has relatively few parameters to be determined, and many registration techniques are not equipped to supply a more complex transformation. The most common application area is the human head.

5.2. Affine

The affine transformation preserves the parallelism of lines, but not their lengths or their angles. It extends the degrees of freedom of the rigid transformation with a scaling factor for each image dimension and additionally, a shearing in each dimension. In P. Viola et al and in, M. Jenkinson et al, an affine registration with nine degrees of freedom is performed to correct calibration errors in the voxel dimensions. Holden et al, further more measured the relative scaling error between scans. R.Shekhar et al.compared registration accuracies of ultrasound images using transformations of increasing complexity (rigid, rigid with uniform scaling, rigid with non uniform scaling and fully affine).

5.3. Projective

Projective transformation is used when the scene appears tilted. Straight lines remain straight, but parallel lines converge toward vanishing points. The projective transformation requires that straight lines in the reference image remain straight in the sensed image. The projective transformation type has no real physical basis in image registration except for 2D/3D registration. It is sometimes used as a "constrained-elastic" transformation, when a fully elastic transformation behaves inadequately or has too many parameters to solve for. The projective transformation is not always used in 2D/3D applications, even though projections will always figure in the problem, the transformation itself is not necessarily projective but may be rigid, if it applies to the 3D image prior to its projection to the 2D image.

5.4. Curved

Several algorithms adapted from computer vision have been proposed and used over time .Gueziec matches the crest lines using a combination of geometric hashing and Hough transform. A 2D-to-3D non-rigid intensity-based planar-to-curved-surface image alignment algorithm was proposed by Smarder Gefan et al. .This algorithm matches experimental data of two dimensional images with their corresponding images overlaid on a curved-surface within a volumetric image. This PDE-based 2D-to-3D registration technique allows for inter-modality matching of sectional data with a volumetric image of homologous objects.

5.5. Diffeomorphic Registration

Diffeomorphisms preserve the topology of the objects and prevent folding which is often physically impossible. They are considered to be a good working framework when no additional information about the spatial transformation is available. The early diffeomorphic registration approaches were based on the "viscous fluid" registration method of Christensen et al. In these models, finite difference methods are used to solve the differential equations that model one image as it "flows" to match the shape of the other. At the time, the advantage of these methods was that they were able to account for large displacements while ensuring that the topology of the warped image was preserved. They also provided a useful foundation from which later methods arose. Viscous fluid methods require the solutions to large sets of partial differential equations. The earliest implementations were computationally expensive because solving the equations used successive over-relaxation. Such relaxation methods are inefficient when there are large low frequency components to estimate. Since then, a number of faster ways of solving the differential equations have been devised. These include the use of Fourier transforms to convolve with the impulse response of the linear regularisation operator, or by convolving with a separable approximation. More recent algorithms for large deformation registration aim to find the smoothest possible solution. For example, the LDDMM (large deformation diffeomorphic metric mapping) algorithm , does not fix the deformation parameters once they have been estimated. It continues to update them using a gradient descent algorithm such that a geodesic distance measure is minimized. In principle, such models could be parameterized by an initial "momentum" field, which fully specifies how the velocities - and hence the deformations evolve over unit time. Unfortunately though, the differential equations involved are difficult to solve, and it is easier to parameterize them using a number of velocity fields corresponding to different time periods over the course of the evolution of the diffeomorphism.

VI. OBJECT

6.1 Head

Automatic registration of images of Head are found in G. Eggers, et al, Al-maveh et al., registered four head and neck images using a biomechanical model. The accuracy of the centre of mass, location of tumor and parotid glands is improved using Deformable Registration. Choonik Lee et-al, .Ching-Fen et-al, Suzanne van Beek et-al Rob.H.et al, developed algorithms for registration of head and neck images for radio therapy treatment planning. Weight loss, tumor shrinkage, and tissue edema induce substantial modification of patient‟s anatomy during head and neck Radiotherapy or chemo-radiotherapy. These modifications may impact on the dose distribution to both Target Volumes and Organs at Risk. Adaptive radiotherapy where patients are re-imaged and re-planned several times during the treatment is a possible strategy to improve treatment delivery. It however requires the use of specific deformable registration algorithms that requires proper validation on a clinical material. Pierre Castadot et al. compared 12 deformable registration strategies in adaptive radiation therapy for the treatment of head and neck tumors.

6.1.1. Brain

In brain imaging, registration is used to study image variations, ranging from inter subject anatomical comparisons, intra-subject monitoring of pathological development, to matching an observed image with a reference template . In cases of intra-subject or temporal variation registration, observed images could be a time series acquired in a short period of time at one occasion, or a time series acquired at several occasions. Research on the improvement of functional-to-anatomical image registration is now focused on finding appropriate correspondences through more general and reliable similarity measures based upon information theory. Spatial and directional information can be incorporated into MI based similarity measure to improve the accuracy of anatomical to functional image registration . Rigid and affine transformations provide practical bases for robust and reliable functional-to-anatomical registration. However, non rigid registration has been proposed to deal with the effect of nonlinear local distortions in functional images, specifically in EPI sequences used for fMRI. Different aspects of brain image registration were discussed in W. Crum. et al, P. Hellier et al, S. Robbins et al, M. Yassa, et al, B. Ardekani et al., V. A. Magnotta et al, Jiangang Liu et al.

6.1.2. Retina

In the case of retinal images, area-based approaches are often used in multimodal or temporal image registration applications. Retinal images are registered by Bin Fang et al.using an elastic matching algorithm with reduced computational load. Thitiporn Chanwimaluang et al. used hybrid method to register retinal images. C.V. Stewart et al used dual-bootstrap iterative closest point algorithm to register retinal images. G.K. Matsopoulos et al., developed an image registration algorithm based on Global Optimization techniques. A new retinal image registration method based on salient feature region was proposed by Jian Zheng et al.

6.1.3. Cardiac

Cardiac image registration remains a challenge because of the numerous problems related to the different motion sources (patient, respiration, heart) and to the specificity of each imaging modality. Up to now, no general method is able to automatically register any modality with any other modality. Cardiac image registration methods always require a compromise among accuracy, precision, reliability, robustness, and issues such as automation, interactivity, speed, patient-friendliness, etc. Rigid cardiac image registration generally does not describe the spatial relationship between images adequately. Elastic (non rigid) cardiac image registration is needed especially because of cardiac motion; between end-diastole and end-systole (during cardiac cycle), the heart valvular plane moves 9 to 14mm toward the apex and the myocardial walls thicken from approximately 10 to over 15mm. Perfusion MR imaging often takes more than three minutes. Breath holding is not possible during the imaging protocol, nor can respiratory gating be used since a high temporal resolution is needed.

6.2. Abdomen

A normalized abdominal coordinate system independent of both the abdomen size and the respiratory motion is defined for abdominal atlas mapping in CT and MR volume images was developed by Hongkai Wang et al. Camara,et al., used a hierarchical segmentation based approach using several thoracic and abdominal structures of CT and emission PET images to initialize a non-linear registration procedure, between these complementary imaging modalities. A novel neuro-fuzzy hybrid transformation model for deformable image registration in intra-operative image guided procedures involving large soft tissue deformation was proposed by Xishi Huang et al.

VII. CONCLUSIONS

The Image registration is one of the most important tasks when integrating and analyzing information from various sources It is a key stage in image fusion, change detection, super-resolution imaging, and in building image information systems, among others. This paper gives a survey of the classical and recent registration methods, classifying them according to their nature as well as according to the four major registration steps. Although a lot of work has been done, automatic image registration still remains an open problem. Also, the problems due to imaging conditions, different movement artifacts, and elasticity of the body, lungs, and heart which cause different tissue deformations that are not possible to model using rigid registration methods. There is considerable research going on in extending the use of intensity-based registration algorithms to non rigid transformations. Registration of images with complex nonlinear and local distortions, multimodal registration, and registration of N-Dimensional images belong to the most challenging tasks at this moment. The major difficulty of N-Dimensional image registration resides in its computational complexity. Although the speed of computers has been growing the need to decrease the computational time of methods persists. The complexity of methods as well as the size of data still grows (the higher resolution, higher dimensionality, larger size of scanned areas). Moreover, the demand for higher robustness and accuracy of the registration usually enforces solutions utilizing the iterations or backtracking, which also produces increase of computational complexity of the method Ultrasound images have been largely ignored by image registration researchers up until now, the increasing quality of ultrasound images and its low cost makes this a fertile area for both intra modality and inter modality applications.

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