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Deformable Registration Techniques for Thoracic CT Images

An Insight into Medical Image Registration

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Chapter 1
Introduction

1.1 Background

Image Registration is defined as the process of establishing correspondences between two images. It is the process of aligning images so that corresponding features can easily be related and the best structural superimposition can be achieved. The term is also used to mean aligning images with a computer model or aligning features in an image with locations in physical space. The images might be acquired with different sensors (e.g., sensitive to different parts of the electromagnetic spectrum) or the same sensor at different times. The present differences between images are introduced due to different imaging conditions. Image registration is a crucial step in all image analysis tasks in which the final information is gained from the combination of various data sources like in image fusion, change detection, and multichannel image restoration. Typically, registration is required in remote sensing (multispectral classification, environmental monitoring, change detection, image mosaicing, weather forecasting, creating super-resolution images, integrating information into geographic information systems [GIS]), in medicine (combining computer tomography [CT], and NMR data to obtain more complete information about the patient, monitoring tumor growth, treatment verification, comparison of the patient's data with anatomical atlases), in cartography (map updating), and in computer vision (target localization, automatic quality control), to name a few. In general, its applications can be divided into four main groups depending upon the manner of image acquisition:

Acquisition from different viewpoints (multi-view analysis): In this category images of the same scene are acquired from different viewpoints/angles. The aim is to gain a larger two-dimensional view or a three-dimensional representation of the scanned/acquired scene. Some examples are computer vision-shape recovery (shape from stereo), Remote sensing-mosaicing of images of the surveyed area, etc., some examples are shown in Figs. 1.1 and 1.2.

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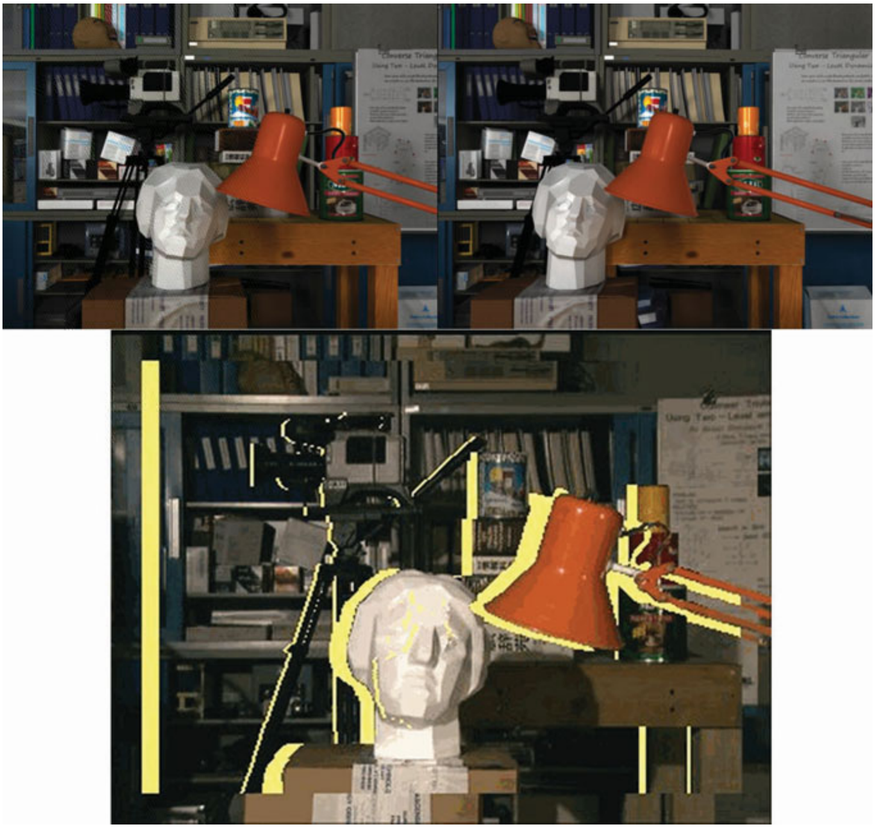

Fig. 1.1 Multi-view capture of the same scene and its registered image showing the difference between two viewpoints. (Used from the original "head and lamp" stereo scene pair along with the transition released by University of Tsukuba in 1997 comprises the Tsubuka stereo dataset [1800 stereo pairs] http://www.cvlab.cs.tsukuba.ac.jp/dataset/tsukubastereo.php)

Images acquired at different timestamps (multi-temporal image analysis): In this categorization, images of the same scene are acquired at different times from the same viewing angle and same acquisition apparatus, often on regular basis and possibly under different conditions. The aim is to find and evaluate changes in the scene which seem to have happened between the consecutive image acquisitions. Some of the examples are remote sensing-monitoring of global land usage, landscape planning, computer vision-automatic change detection for security monitoring, motion tracking. Medical imaging based monitoring of the healing therapy, monitoring of the tumor evolution, etc. Some examples are shown using Figs. 1.3, 1.4 and 1.5.

Images acquired using different sensors (multi-modal analysis): When images of the same scene are acquired by different sensors while muting other variables such as time gap, viewing angle, etc., and analyzed, it falls into the multi-modal analysis category. The aim is to integrate the information obtained from different source streams

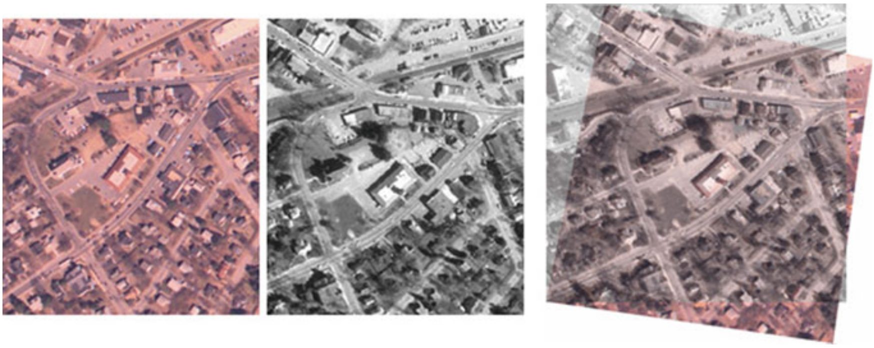

Fig. 1.2 Another sample that can be taken as an example for multi-view image registration; first two are the aerial shots of a single scene at different angles, third is the registered image. (A digital aerial photograph [geometrically uncorrected] to a digital orthophoto [supplied by the Massachusetts Geographic Information System (MassGIS), has been orthorectified] covering the same area centered on the business district of West Concord, Massachusetts, USA https://in.mathworks.com/discovery/image-registration.html)

Fig. 1.3 Registration of two images with temporal change (lesser number of trailers parked) (http://old.vision.ece.ucsb.edu/registration/demo/ex3.shtml)

to gain more complex and detailed scene representation. Examples of applications: Remote sensing-fusion of information from sensors with different characteristics like panchromatic images, offering better spatial resolution, color/multispectral images with better spectral resolution, or radar images independent of cloud cover and solar illumination. Medical imaging-combination of sensors recording the anatomical body structure like magnetic resonance image (MRI), ultrasound, or CT with sensors monitoring functional and metabolic body activities like positron emission tomography (PET), single-photon emission computed tomography (SPECT), or magnetic resonance spectroscopy (MRS). Results can be applied, for instance, in radiotherapy and nuclear medicine. Some examples are shown in Figs. 1.6, 1.7 and 1.8.

Fig. 1.4 Two years temporal progress of deforestation can be observed in Amazonian Rainforests (http://old.vision.ece.ucsb.edu/registration/demo/ex4.shtml)

Scene to model registration: When images of a scene are registered with a computer-generated model of that scene. This model can be a visual representation of the scene, for instance, maps or digital elevation models (DEM) in GIS, another scene with similar content (e.g., another patient), "average" specimen, etc. The aim is to localize the acquired image in the scene/model and/or to compare them. Some examples are remote sensing-registration of aerial or satellite data into maps or other GIS layers. Creating Panoramas from the end to end stitching of acquired images. In computer vision, target template matching with real-time images, automatic quality inspections, etc. are good examples. In case of medical imaging, a comparison of the patient's image with digital anatomical atlases, specimen classification is an application. An example of image stitching is depicted in Fig. 1.9.

Though there can be more, usually there are two images involved in the process of image registration. One of them is called the moving image denoted by M or source image and is denoted by S, this image is to be registered against a fixed image indicated as F or a target image denoted by T. An example has been shown in Fig. 1.10. Image registration can also be explained in terms of forward transform mapping, i.e., mapping of points from the physical space of the fixed image into the physical space of the moving image. This is shown in Fig. 1.11.

This implies that the transform will accept as input points from the fixed image and it will compute the coordinates of the analogous points in the moving image. What tends to create confusion is the fact that when the transform shifts a point on the positive X direction, the visual effect of this mapping, once the moving image is re-sampled, is equivalent to manually shifting the moving image along the negative X direction. In the same way, when the transform applies a clock-wise rotation to the fixed image points, the visual effect of this mapping once the moving image has been re-sampled is equivalent to manually rotating the moving image counter-clock-wise. The reason why this direction of mapping has been chosen for implementation of registration framework widely is that this is the direction that better fits the fact that the moving image is expected to be re-sampled using the grid of the fixed image.

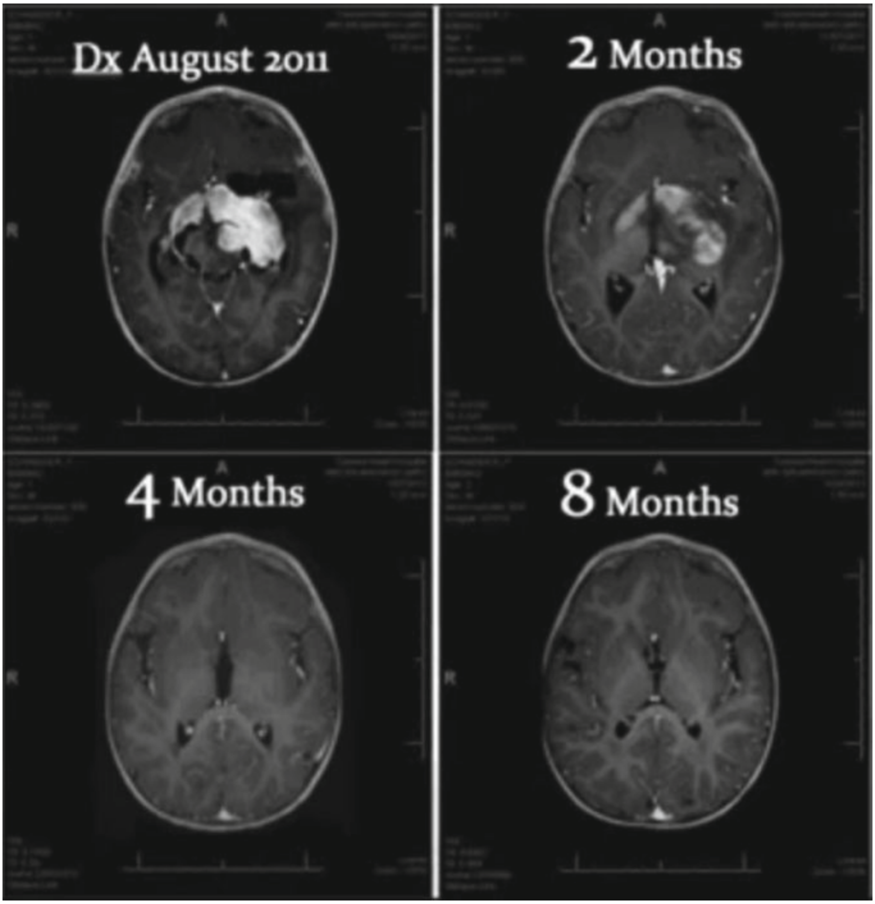

Fig. 1.5 Brain tumor (cancerous) size reduction over a time of 8 months for a baby diagnosed at 8 months of age (http://www.inquisitr.com/423292/babys-brain-tumor-gone-after-dad-puts-marijuana-on-pacifier-video/)

The nature of the re-sampling process is such that an algorithm must go through every pixel of the fixed image and compute the intensity that should be assigned to this pixel from the mapping of the moving image. This computation involves taking the integral coordinates of the pixel in the image grid, usually called the "(i, j)" coordinates, mapping them into the physical space of the fixed image (transform T1 in Fig. 1.11), mapping those physical coordinates into the physical space of the moving image (transform to be optimized), then mapping the physical coordinates of the moving image into the integral coordinates of the discrete grid of the moving image (transform T2 in the figure), where the value of the pixel intensity will be computed by interpolation.

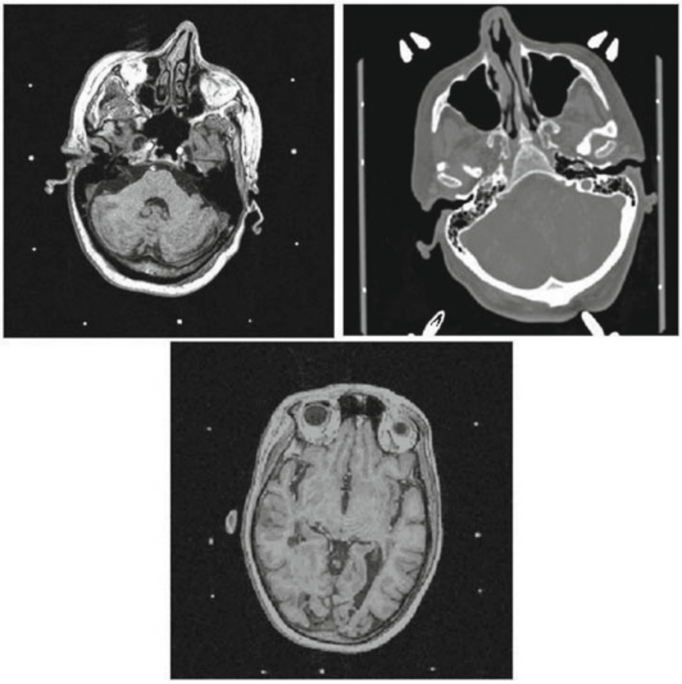

Fig. 1.6 MRI and CT image representation of the same axial section showing soft tissues and bony structures, respectively. The third is fusion of these both images finding the most optimal transformation (http://docplayer.net/21680192-Image-registration-and-fusion-professor-michael-brady-frs-freng-department-of-engineering-science-oxford-university.html)

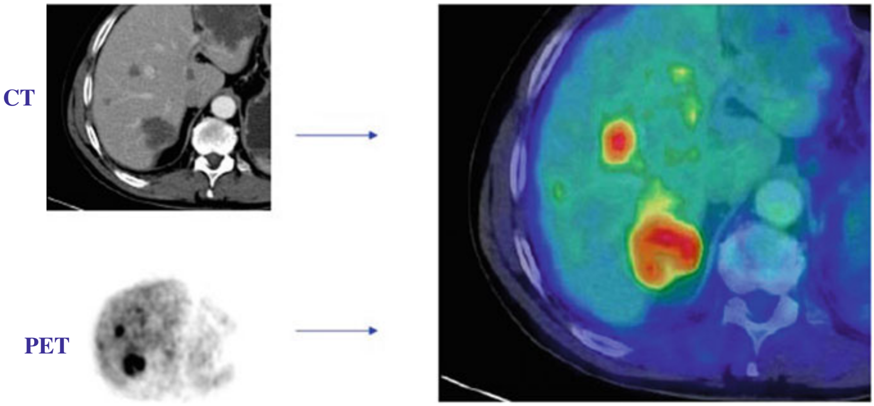

Fig. 1.7 CT image, PET image, and fusion of both coronal slices of the thoracic section to find the best view possible (http://docplayer.net/21680192-Image-registration-and-fusion-professor-michael-brady-frs-freng-department-of-engineering-science-oxford-university.html)

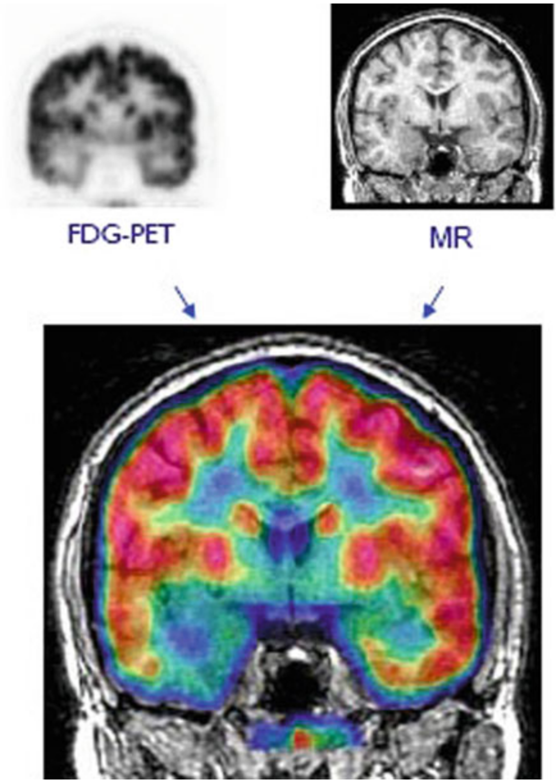

Fig. 1.8 PET image, MR image volume, and fusion of both coronal slices of the human brain to find the best representation possible (http://docplayer.net/21680192-Image-registration-and-fusion-professor-michael-brady-frs-freng-department-of-engineering-science-oxford-university.html)

Registration of a moving image $I_M(x, y)$ to a fixed image $I_F(x, y)$ both of dimension D, is the problem of finding a displacement field $u(x)$ that makes $I_M(x + u(x))$ spatially aligned to $I_F(x)$. The obtained transformation is defined as

$$T(x) = x + u(x)$$

If the underlying transformation model allows local deformations, i.e., nonlinear displacement fields $u(x)$, then it is called Deformable Image Registration (DIR).

1.2 Motivation

Many exciting potential applications of deformable image registration (DIR) have been found in diagnostic medical imaging and radiation oncology. Automated propagation of physician-drawn contours to multiple image volumes, functional imaging,