Registration of Static and Dynamic Biomedical Image Data

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Introduction: Matching and Registration of Images
Image Matching

Image matching is the process of establishing correspondences between objects in images.

Original images and contours

Some of the correspondences found

Image Registration

Image registration is the process of searching for the best transformation that change one image in relation to another image in order to correlated features assume similar locations in a common space.

Template (or fixed) image

Source (or moving) image

Overlapped images before and after the registration

Image Registration

Applications

- Supporting surgical interventions (more efficient localization of lesions, find alignments between devices and patients, etc.)
- Optimizing radio-therapeutic treatments
- Automatic recognition of organs/tissues (support complex tasks of image segmentation and identification, etc.)
- Building of Atlas (with well-known cases used for comparison)
- Simplifying posterior statistical analysis (SPM, Z-scores, etc.)
- Simplifying image-based diagnosis
  - Fusion of images from different imaging modalities (CT/PET, MRI/CT, SPECT/CT, MRI/PET, …)
  - Follow-up of pathologies
- …
Image Registration

In the last years, considerable research has been done concerning biomedical data registration. The methodologies can be classified based on different criteria:

- **Data dimensionality**: 2D/2D, 2D/3D, 3D/3D, 2D/3D + Time

- **Features used**: extrinsic (using features external to the patient) or intrinsic (using information from the patient; e.g. pixel intensity values, relevant points, contours, regions, skeletons, surfaces, …)

  - **Interaction**: manual, semiautomatic or automatic

  - …
Image Registration

... cont.

– Transformation type: rigid, similarity, affine, projective, curved
– Transformation domain: local or global
– Modalities involved: same modality (CT/CT, MRI/MRI, PET/PET, …), different modalities (CT/MRI, MRI-T1/MRI-T2, PET/CT, …) or patient/model (e.g. between a patient and an atlas or between a patient and a device)
– Subjects: registration of images from the same subject or from different subjects, or images of a subject with images in an atlas
– Organs/tissues involved: brain, liver, etc.
– ...

Image Registration

In the last years, we have been developing methods for image matching and registration based on different techniques and applied them in several applications

- Techniques
  - Based on features (points, contours) extracted from the images and based on the intensity of the pixels (or voxels)
  - By computing the optimal registration transformation directly or iteratively
  - By using different transformation models

- Data
  - Images from the same patient, different patients and atlas
  - Images from the same or different imaging modalities
  - Registration of 2D and 3D images, and of 2D image sequences
Methods: Spatial Registration of 2D and 3D images
Registration based on Contours Matching

- Fixed image
  - Extract the contours
  - Assemble the matching cost matrix
  - Search for the optimal matching
  - Compute the geometric transformation
  - Register the moving image

The cost matrix is built based on geometric or physical principles.

The matching is found based on the minimization of the sum of the costs associated to the possible correspondences.

To search for the best matching is used an optimization assignment algorithm.

Registration based on Direct Maximization of the Cross-Correlation

The scaling and rotation are obtained from the spectrum images after their conversion to the log-polar coordinate system.

The algorithm searches for the geometric transformation involved using the shift, scaling and rotation properties of the Fourier transform.

… Also based on the Fourier transform

- Registration based on Direct Minimization of the Sum of Squared Differences

- Registration based on the Phase Correlation Technique

Both algorithms are quite similar to the Cross-Correlation based algorithm; the difference is the similarity measure used

Registration **based on Iterative Optimization**

Based on the iterative search for the parameters of the transformation that optimizes a similarity measure between the input images.

The optimization algorithm stops when a similarity criterion is achieved.

Registration **using Iterative Optimization and a curved transformation based on B-splines**

- **Fixed image**
- **Moving image**

  - Pre-registration using a **rigid transformation**
  - New **pre-registration using an affine transformation**
  - Coarse registration based on B-splines
  - Fine registration based on B-splines

  **Registered moving image**

*The registration based on B-splines is of the free-form deformation type*
Registration based on Iterative Optimization

To speedup the computational process, a multi-resolution strategy is frequently used.
Methods: Spatio & Temporal Registration
Spatio & Temporal registration of image sequences

Applications and Results: Plantar Pressure Images
Registration **based on Contours Matching**

I - Contours extraction and matching

**Fixed image and contour**  
(optical plantar pressure device)

**Moving image and contour**  
(optical plantar pressure device)

**Matching established**
Registration based on Contours Matching

... cont.

II - Registration

Registration: 2D, monomodal, intrasubject

Processing time: 0.125 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 160x288 pixels
Registration based on Direct Maximization of the Cross-Correlation

Registration: 2D, monomodal, intrasubject (on the top) and intersubject (on the bottom)

Processing time: 0.04 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 45x63 pixels

Using a rigid transformation

Using a similarity transformation
Spatio & Temporal registration of Plantar Pressure Image Sequences

Device: EMED (25 fps, resolution: 2 pixels/cm², images dimension: 32x55x13; 32x55x18)

Registration: rigid (spatial), polynomial (temporal); similarity measure: MSE

Processing time: 4 s - AMD Turion64, 2.0 GHz, 1.0 GB of RAM

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<th>Overlapped sequences</th>
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Applications in Plantar Pressure Images Studies

A computational solution, device independent, has been developed to assist studies based on the registration of plantar pressure images:

– Foot segmentation
– Foot classification: left/right, high arched, flat, normal, …
– Foot axis computation
– Footprint indices computation
– Posterior statistical analysis

Applications and Results: Medical Images
Registration based on Contours Matching

Registration: 2D, monomodal, intrasubject

Processing time: 0.5 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 217x140 pixels

Fixed image and contour (MRI)  Moving image and contour (MRI)  Correspondences found between Corpus Callosum contours

Overlapped images before the registration  Overlapped images after the registration  Difference between the images after the registration
Registration based on Direct Maximization of the Cross-Correlation

Registration: 2D, monomodal, intrasubject

Processing time: 2.1 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 221x257 pixels
Registration based on Iterative Optimization

Registration: 2D, multimodal, intrasubject (without pre-registration)

Similarity measure: MI

Processing time: 4.6 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 246x234 pixels
Registration based on Iterative Optimization

“Checkerboard” of the slices before the registration (CT/MRI-PD, brain)

The “checkerboard” slice is built by interchanging square patches of both slices and preserving their original spatial position in the fixed (F) and moving (M) slices.
Registration based on Iterative Optimization

... cont.

*Checkerboard of the slices after the registration (CT/MRI-PD, brain)*

Registration: 3D, multimodal, intrasubject; Similarity measure: MI
Registration using Iterative Optimization

Checkerboard of the slices (CT, thorax, Δt: 8.5 months) before the registration
Registration using Iterative Optimization

... cont.

Checkerboard of the slices (CT, thorax, Δt: 8.5 months) after a rigid registration

Registration: 3D, monomodal, intrasubject; Similarity measure: MI
Registration using Iterative Optimization

... cont.

Checkerboard of the slices (CT, thorax, Δt: 8.5 months) after a cubic B-spline registration

Registration: 3D, monomodal, intrasubject; Similarity measure: MI
Application in DaTSCAN SPECT image studies

Brain DaTSCAN SPECT images are used to assist the diagnosis of the Parkinson’s disease and to distinguish it from other degenerative diseases. The solution developed is able to:

– Segment the relevant areas and perform dimensional analysis
– Quantify the binding potential of the basal ganglia
– Automatic computation of statistical data regarding a reference population

Normal  Alzheimer  Idiopathic Parkinsonism  Essential tremor
Application in DaTSCAN SPECT image studies

3D volume images are automatically registered and statistical analysis relatively to a reference population can be accomplished.

*Mean slice from the population used as reference*
*Corresponding slice of a patient*
*Difference of intensities*
*Z-scores mapping over the slice (red – high Z-scores)*

(The blue rectangles represent the 3D ROIs used to compute the binding potentials)
Application in DaTSCAN SPECT image studies

Basal ganglia 3D shape reconstruction and quantification

Application in SPECT/CT registration and fusion

Three slices (coronal, sagittal and axial) after registration and identification of the lesion

3D visualization after fusion CT/SPECT (the lesion identified in the SPECT slices is indicated)
Application in 3D Reconstruction from multiple views

Axial and sagittal T2-weighted MR images

3D Reconstructions of the bladder using data from the axial view, from both views and from sagittal view

Ma, Jorge, Mascarenhas, Tavares (2013) Medical Engineering & Physics DOI:10.1016/j.medengphy.2013.05.002
Conclusions
Conclusions

• Hard efforts have been made to develop methods more robust and efficient to register images
• The Biomedical area has been one of the major promoters for such efforts; particularly, due to the requirements in terms of low computational times, robustness and of complexity of the structures involved
• We have been developing several methods that have been successfully applied
• However, several difficulties still to be overcome and better addressed; such as, severe non-rigidity, complex spatio & temporal behaviors, high differences between the images to be registered (e.g. from very dissimilar image sources), etc.
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  – PDTC/SAU-BEB/71459/2006
  – POSC/EEA-SRI/55386/2004
Events & Publications
Welcome!

- PhD and Pos-Doc Grants: See Offers, UPDATE (11/09/11)

Book Series: Lecture Notes in Computational Vision and Biomechanics
Editors: João Manuel R. S. Tavares, R. M. Natal Jorge
ISSN: 2212-9391
Publisher: Springer
Flyer: in.pdf

Book Proposals are Welcome!

VIP Image
Taylor & Francis journal “Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization”
Lecture Notes in Computational Vision and Biomechanics (LNCV&B)  
Series Editors: João Manuel R. S. Tavares, Renato Natal Jorge  
ISSN: 2212-9391  
Publisher: SPRINGER

http://www.springer.com/series/8910
ViplIMAGE2013 - IV ECCOMAS Thematic Conference on Computational Vision and Medical Image Processing
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http://www.fe.up.pt/vipimage
Thank you!

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