Biomedical Image Analysis based on Computational Image Registration Methods

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Introduction
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*

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Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93
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.)
- **Building of Bio-signatures**
- **Simplifying image-based diagnosis**
  - Fusion of images from different imaging modalities (CT/PET, MRI/CT, SPECT/CT, MRI/PET, …) or points of view
  - Follow-up of pathologies, etc.
Image Registration

In the last years, we have developed methods for image 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 directly or iteratively the optimal registration transformation
  • By using different transformation models

– Data
  • Images from the same patient, different patients and atlas
  • Images from the same or different imaging modalities or different points of view
  • 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**
- **Moving image**

1. Extract the contours
2. Assemble the matching cost matrix
3. Search for the optimal matching
4. Compute the geometric transformation
5. Register the moving image

**Registered 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

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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.

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.

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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*

Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93
Methods: Spatio & Temporal Registration
Spatio & Temporal registration of image sequences

**Fixed sequence**
- Compute the similarity measure
  - Optimizer

**Moving sequence**
- Apply the spatio & temporal transformation
  - Build the spatio & temporal transformation

**Registration optimization**
- Build the temporal representative images
  - Search for the transformation that register the temporal representative images

**Pre-registration**
- Estimate the linear temporal registration

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

I - Contours extraction and matching

Fixed image and contour (optical plantar pressure device)  Matching established

Moving image and contour (optical plantar pressure device)
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

**Images from the same foot**

**Images from different subjects**
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

<table>
<thead>
<tr>
<th>Fixed sequence</th>
<th>Moving sequence</th>
<th>Overlapped sequences</th>
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Before the registration

After the registration

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Biomedical Image Analysis based on Computational Image Registration Methods
Applications in Plantar Pressure Images Studies

A computational solution 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

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Registration based on Direct Maximization of the Cross-Correlation

**Fixed image**
MRI (proton density)

**Moving image**
MRI (proton density)

**Overlapped images before the registration**

**Overlapped images after the registration**

**Sum of the images after the registration**

**Difference of the images after the registration**

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

**Fixed image (CT)**

**Moving image (MRI)**

**Overlapped images before the registration**

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

**Overlapped images after the registration**

**Sum of the images after the registration**

**Difference of the images after the registration**

Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93
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 based on Iterative Optimization

Checkerboard of the slices (CT, thorax, Δt: 8.5 months) before the registration

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Registration based on Iterative Optimization

... cont.

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

Registration: 3D, monomodal, intrasubject; Similarity measure: MI
Application in Brain DaTSCAN SPECT images

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
– Computation of statistical data relatively to a reference population
– Classification to support the diagnosis

![Normal](image1)
![Alzheimer](image2)
![Idiopathic Parkinsonism](image3)
![Essential tremor](image4)
Application in Brain DaTSCAN SPECT images

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

Application in Brain DaTSCAN SPECT images

Basal ganglia 3D shape reconstruction and quantification

Basal ganglia from a mean image of a normal population

Basal ganglia from a patient with idiopathic Parkinson’s disease

Basal ganglia from a patient with vascular Parkinson’s disease

Application in SPECT/CT registration and fusion

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

3D visualization after CT/SPECT fusion (the lesion identified in the SPECT slices is indicated)
Application in Ear CT images

Application in the fully automated segmentation of the incus and malleus ear ossicles in conventional CT images

Application in 3D Reconstruction from multiple views

Axial and sagittal T2-weighted MR images

3D Reconstruction of the bladder by fusion data from the axial and sagittal images (2 views)

Ma et al. (2013) Medical Engineering & Physics 35(12):1819-1824
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 developed several methods that have been successfully applied in different applications.
- 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.
Acknowledgments

• The work presented has been done with the support of Fundação para a Ciência e a Tecnologia, in Portugal, mainly through the funding of the research projects:
  – PTDC/BBB-BMD/3088/2012
  – PTDC/SAU-BEB/102547/2008
  – PTDC/SAU-BEB/104992/2008
  – PTDC/EEA-CRO/103320/2008
  – UTAustin/CA/0047/2008
  – UTAustin/MAT/0009/2008
  – PDTC/EME-PME/81229/2006
  – PDTC/SAU-BEB/71459/2006
  – POSC/EEA-SRI/55386/2004
Taylor & Francis journal “Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization”

Editor-in-Chief:
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Obrigado!

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