Biomedical Image Analysis based on Computational Registration Methods

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Outline

1. Introduction

2. Methods
   a) Spatial Registration of (2D & 3D) Images
   b) Spatio & Temporal Registration (2D image sequences)

3. Applications and Results
   a) Plantar Pressure Images (2D static images & 2D image sequences)
   b) Medical Images (2D & 3D)

4. Conclusions
Introduction
Image Registration

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

Overlapped images before and after the registration

Template (or fixed) image

Source (or moving) image

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.)
- **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
- …
In the last years, we have developed 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 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

- Extract the contours
- Assemble the matching cost matrix
- Search for the optimal matching
- Compute the geometric transformation
- 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.

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.

*Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93*
Registration using Iterative Optimization and a curved transformation based on B-splines

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
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

Build the temporal representative images

Search for the transformation that register the temporal representative images

Estimate the linear temporal registration

Registration optimization

Pre-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)*

*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

- **Fixed image**
- **Moving image**
- **Overlay images before and after the registration**

Images from the same foot

Images from different subjects

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

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

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Biomedical Image Analysis based on Computational Registration Methods
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

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

<table>
<thead>
<tr>
<th>Fixed image (CT)</th>
<th>Moving image (MRI)</th>
<th>Overlapped images before the registration</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Overlapped images after the registration" /></td>
<td><img src="image2" alt="Sum of the images after the registration" /></td>
<td><img src="image3" alt="Difference of the images after the registration" /></td>
</tr>
</tbody>
</table>

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

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

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

Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93
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
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
Application in Brain DaTSCAN SPECT images

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)

Application in Brain DaTSCAN SPECT images

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 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 gated myocardial perfusion SPECT images

Fully automated segmentation and classification of gated myocardial perfusion SPECT images based on image registration and an artificial classifier

**Diagram:**

1. Data Registration
   - Definition of fixed and moving images
   - Pre-processing with image interpolator and normalization
   - Pre-registration based on rigid transform
   - Registration based on deformable transform

2. Segmentation and (3) quantitative analysis
   - Post-processing using morphological operations
   - Segmentation using Otsu multiple thresholds
   - Registration of the segmented slices with the coronary mapping of the template image
   - Quantitative image analysis: computation of geometric dimensions and statistical analysis

3. Image classification
   - Training vectors
   - Test vectors
   - Bayesian classifier

**Notes:**

Template image (top), segmented image (bottom-left) and artery mapping (bottom-right)
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.
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20 – 25 July 2014 - Barcelona, Spain

5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)

Mini-Symposium "Computational Bioimaging and Visualization"

Mini-Symposium "Computational Bio- Imaging and Visualization"

Rodos Palace Hotel, Rhodes, Greece, 22-28 September 2014
Webpage (www.fe.up.pt/~tavares)
Thank you!

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