Analysis of Medical Images based on Computational Methods of Image Registration

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Presentation

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• Research Areas: Image Processing and Analysis, Medical Imaging, Biomechanics, Human Posture and Control, Product Development
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: 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 Matching

Matching based on **physical or geometrical modeling**

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*

Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93
Image 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 or voxel intensity, 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.
– …

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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, analysis 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
- …
Image Registration

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

Fixed image

Moving image

- 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.

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 based on Iterative Optimization

To speed up the computational process, a multi-resolution strategy is frequently used.
Methods: Spatio & Temporal Registration
Spatio & Temporal registration based on Iterative Optimization

**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
- Estimate the linear temporal registration

**Pre-registration**

Applications and Results: Plantar Pressure Images
A plantar pressure image is a data set that conveys the interaction between the foot sole and the ground.

Static pressure images: from a plate with an array of piezoelectric sensors (left) and from a light reflection device (right).
Plantar Pressure Images

A dynamic plantar pressure image sequence represents the interaction between the foot sole and the ground during a complete step.

Example of a footstep sequence acquired at normal walking speed:

An EMED® plate and an example of an image sequence acquired.
Plantar Pressure Images

A dynamic plantar pressure image sequence represents the interaction between the foot sole and the ground during a complete step.

Example of a footstep sequence acquired at normal walking speed:

Scheme of a light reflection device and an original image sequence acquired and the corresponding segmented image sequence.
Applications of Plantar Pressure Image Analysis

The automated analysis of plantar pressure images is useful in laboratories and clinics

• To facilitate the automatic computation of several statistical measures that can be used to study foot pressure distributions (e.g. diabetic foot)

• For building mean plantar pressure images that are more accurate to represent the pressure distribution than only trial images or image sequences

• To simplify usual diagnosis tasks, such as foot classification, foot main regions identification, comparison between feet of different subjects
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

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 based on Direct Maximization of the Cross-Correlation

Registration: 2D, monomodal, inrasubject (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
Spatio & Temporal registration of Plantar Pressure Image Sequences

Device: Light reflection (25 fps, resolution 30 pixels/cm²)
Image similarity measure: MSD
Sequences dimension: 160x288x22, 160x288x25
Processing time: 1 min (using an AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Before the registration

After the registration

Template sequence  Source sequence  Overlapped sequences
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: MSD

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
Applications in Plantar Pressure Images Studies

A computational solution has been developed to assist biomechanical studies based on the registration of plantar pressure images, which can be used in:

- 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 Turion 64, 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 Fourier transform

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

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 *based on 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 based on Iterative Optimization

... cont.

Checkerboard of the slices (CT, thorax, Δt: 8.5 months) after the registration
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
- Image classification for diagnosis purposes
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)

(The blue rectangles represent the 3D ROIs used to compute the binding potentials)

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 potential 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

TC slices with the incus and malleus ossicles (inside the red ellipse) to be segmented

3D surface of the incus and malleus surface built

Application in Gated Myocardial Perfusion SPECT images

Fully automated segmentation and classification of the images based on image registration and an artificial classifier

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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Research Team (Computational Vision)

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Events & Publications
João Manuel R. S. Tavares
Analysis of Medical Images based on Computational Methods of Image Registration
Lecture Notes in Computational Vision and Biomechanics (LNCV&B) Series Editors: João Manuel R. S. Tavares, Renato Natal Jorge
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Events:

- **M2D’2015**
  6th International Conference on
  **MECHANICS AND MATERIALS IN DESIGN**
  (Ponta Delgada/Azores, 26-30 July 2015)
  Mini-Symposium on
  "Non-destructive Inspection Techniques for
  Materials and Structures"

- **BioMedWomen**
  International Conference on Clinical and BioEngineering for Women’s Health
  20-23 June 2015 - Porto, Portugal

- **Computational Bioimaging**
  A Special Track of the
  10th International Symposium on Visual Computing (ISVC’14)
  http://www.isvc.net
  December 8-10, 2014, Las Vegas, Nevada, USA

- **CMN 2015**
  Congress on Numerical Methods in Engineering
  Instituto Superior Técnico - LISBOA - June 29 to July 2, 2015
  Thematic Session on
  "Image Processing and Visualization"
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