LABORATORY OF OPTICS AND EXPERIMENTAL MECHANICS

Analysis of Medical Images based on Computational Methods of Image Registration

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INFORMÁTICA MÉDICA

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Presentation

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- Senior Research and Projects Coordinator of the Optics and Experimental Mechanics Lab (LOME) of the Institute of Mechanical Engineering and Industrial Management (INEGI)
- PhD and MSc degrees in Electrical and Computer Engineering from FEUP in 2001 and 1995, respectively
- BSc degree in Mechanical Engineering from FEUP in 1992
- Research Areas: Image Processing and Analysis, Medical Imaging, Biomechanics, Human Posture and Control, Product Development

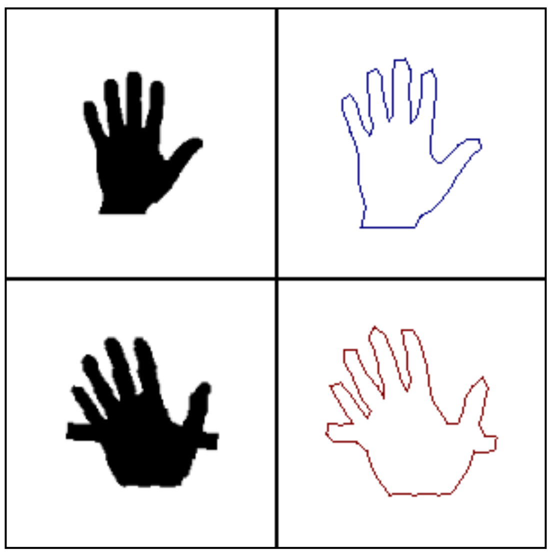
Outline

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

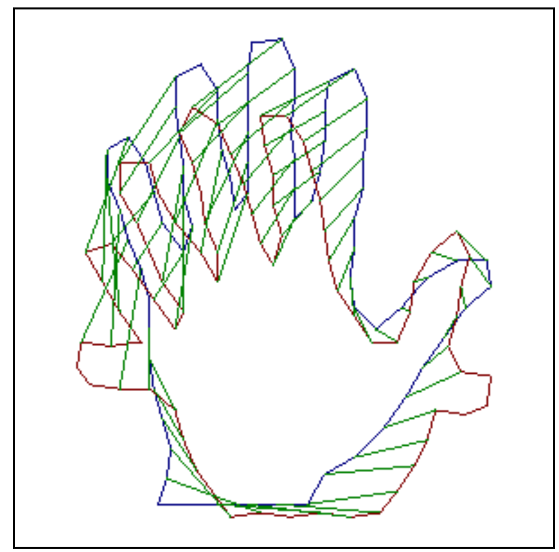
Introduction: Matching and Registration of Images

Image Matching

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



Original images and contours

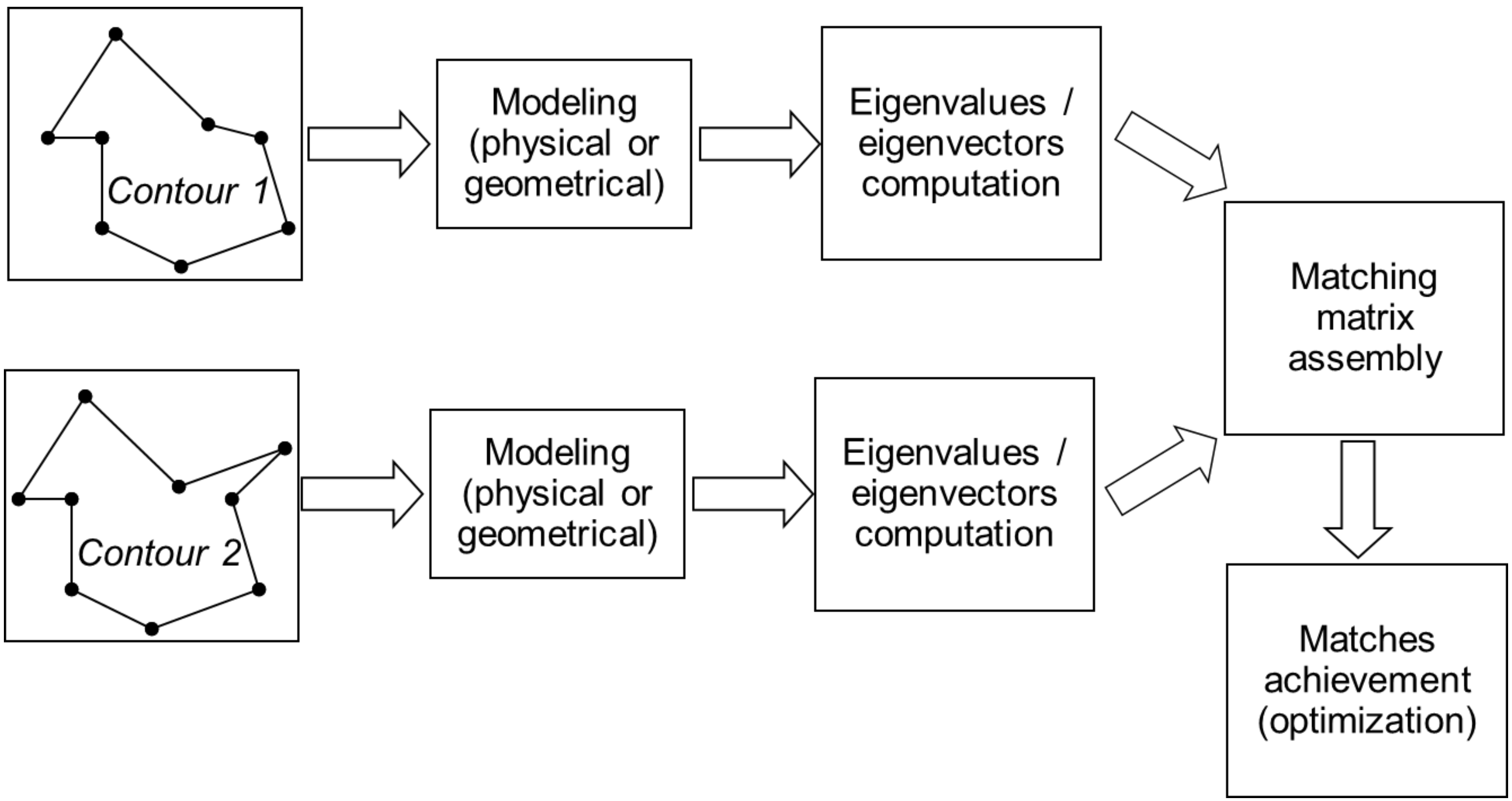


Some of the correspondences found

Bastos & Tavares (2006) Inverse Problems in Science and Engineering 14(5):529-541
Oliveira, Tavares, Pataky (2009) VipMAGE 2009, pp. 269-274

Image Matching

Matching based on **physical or geometrical modeling**

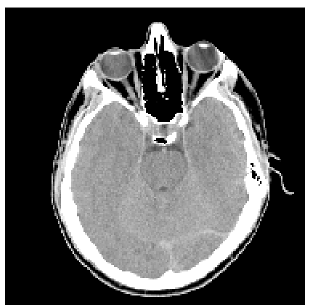


Bastos & Tavares (2006) Inverse Problems in Science and Engineering 14(5):529-541
Oliveira, Tavares, Pataky (2009) VipMAGE 2009, pp. 269-274

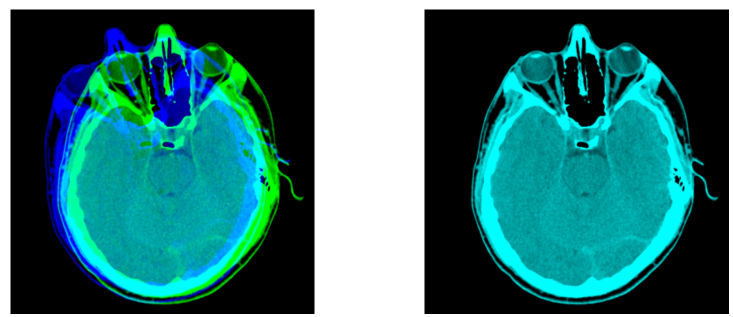
Image Registration

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 **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
- …

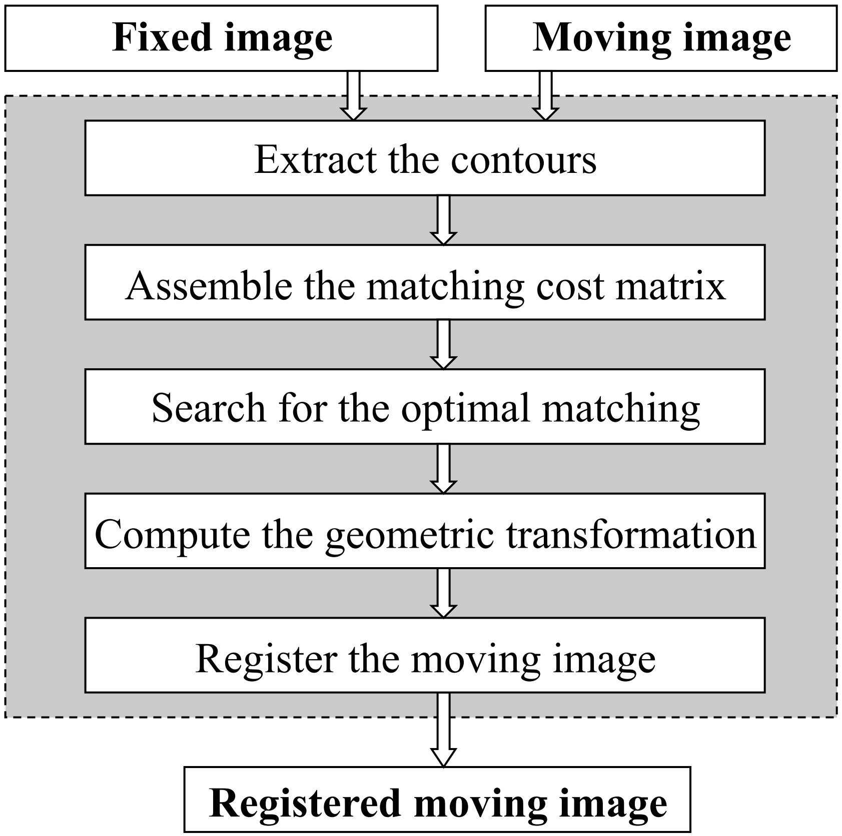
Image Registration

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**



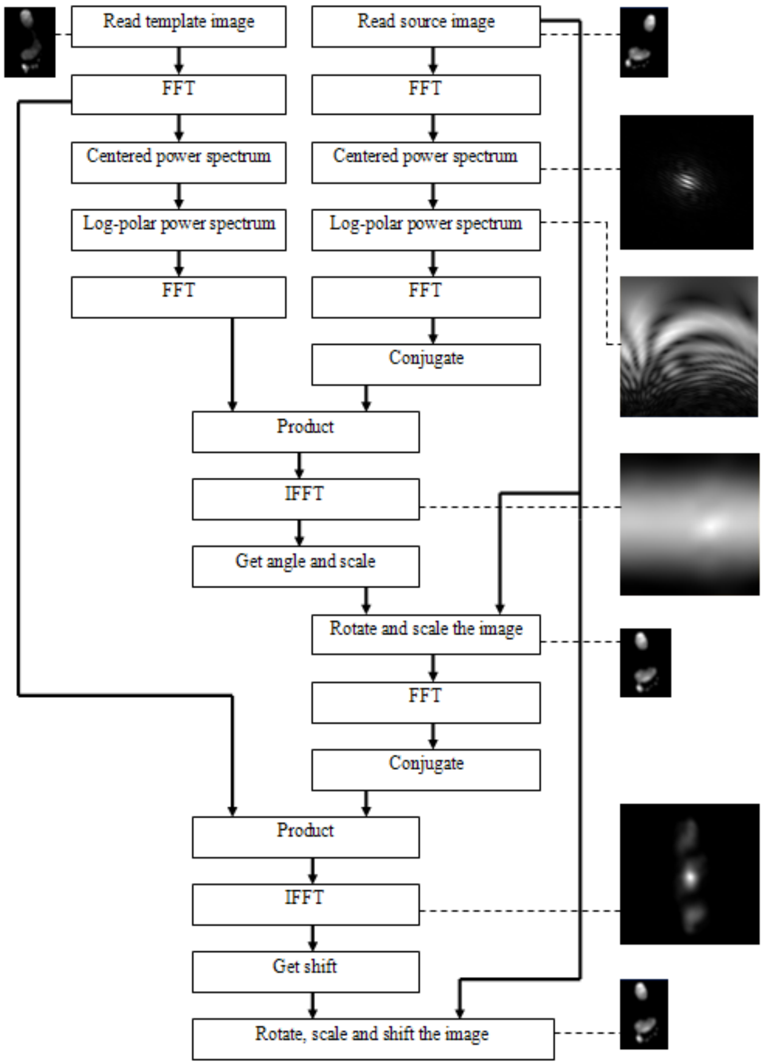
The **cost matrix is built based on geometric or physical principles**

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

Bastos & Tavares (2006) Inverse Problems in Science and Engineering 14(5):529-541
Oliveira & Tavares (2009) Computer Modeling in Engineering & Sciences 43(1):91-110
Oliveira, Tavares, Pataky (2009) Journal of Biomechanics 42(15):2620-2623

Registration **based on Fourier Transform**



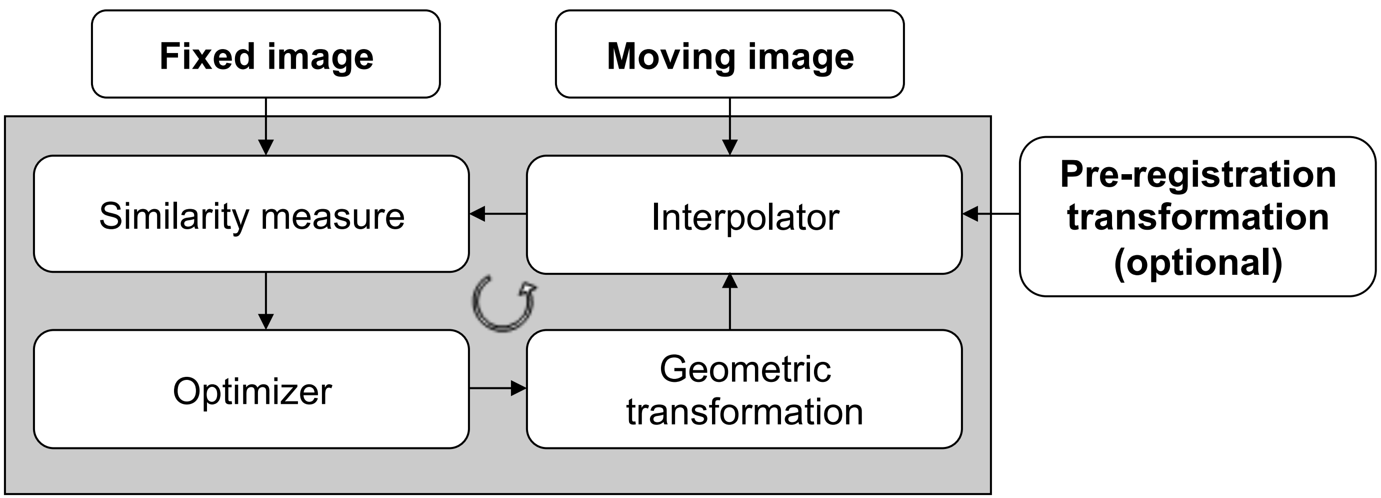
The scaling and rotation are obtained from the spectrum images after their conversion to the log-polar coordinate system

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

Oliveira, Pataky, Tavares (2010) Computer Methods in Biomechanics and Biomedical Engineering 13(6):731-740

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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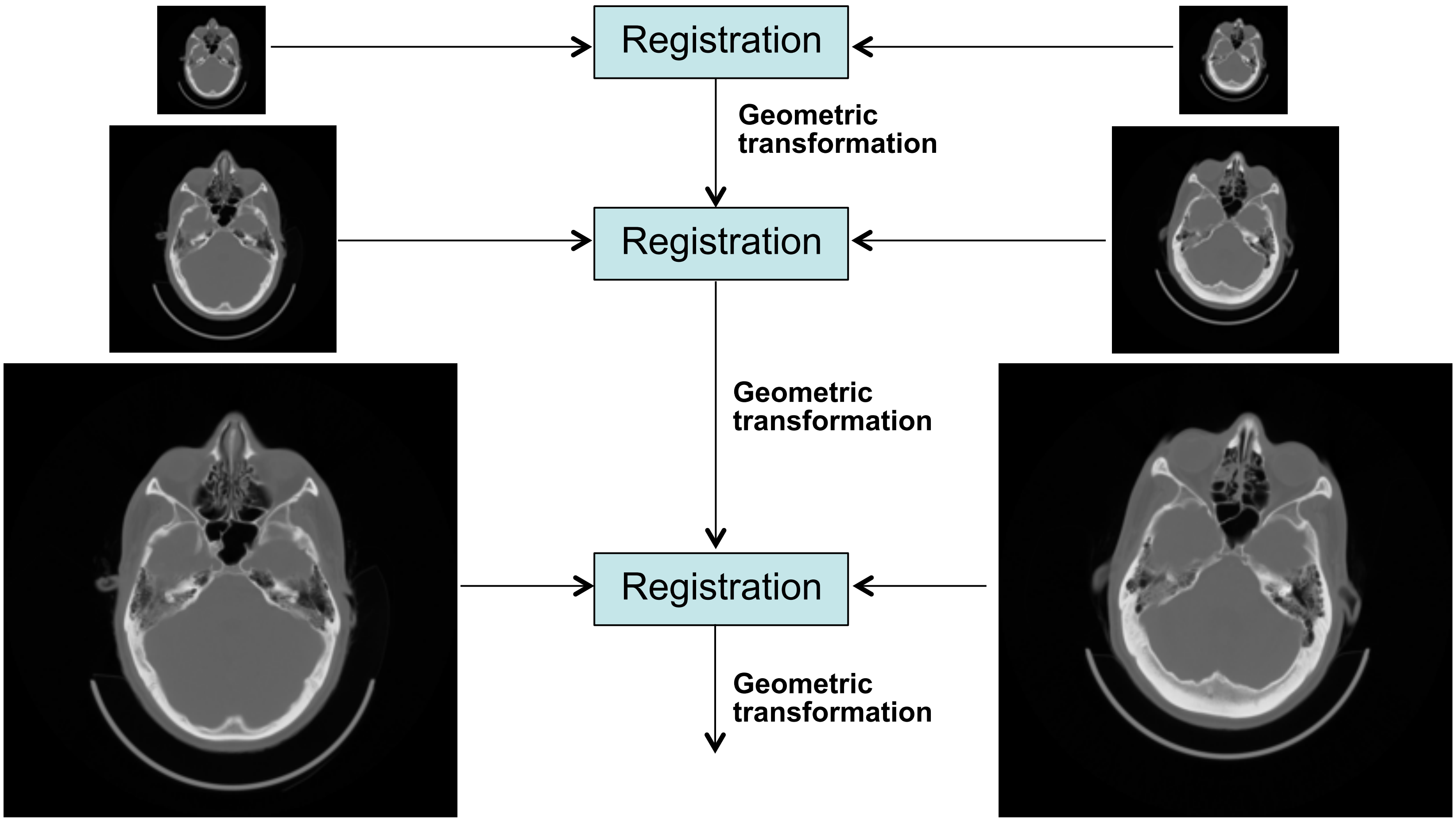
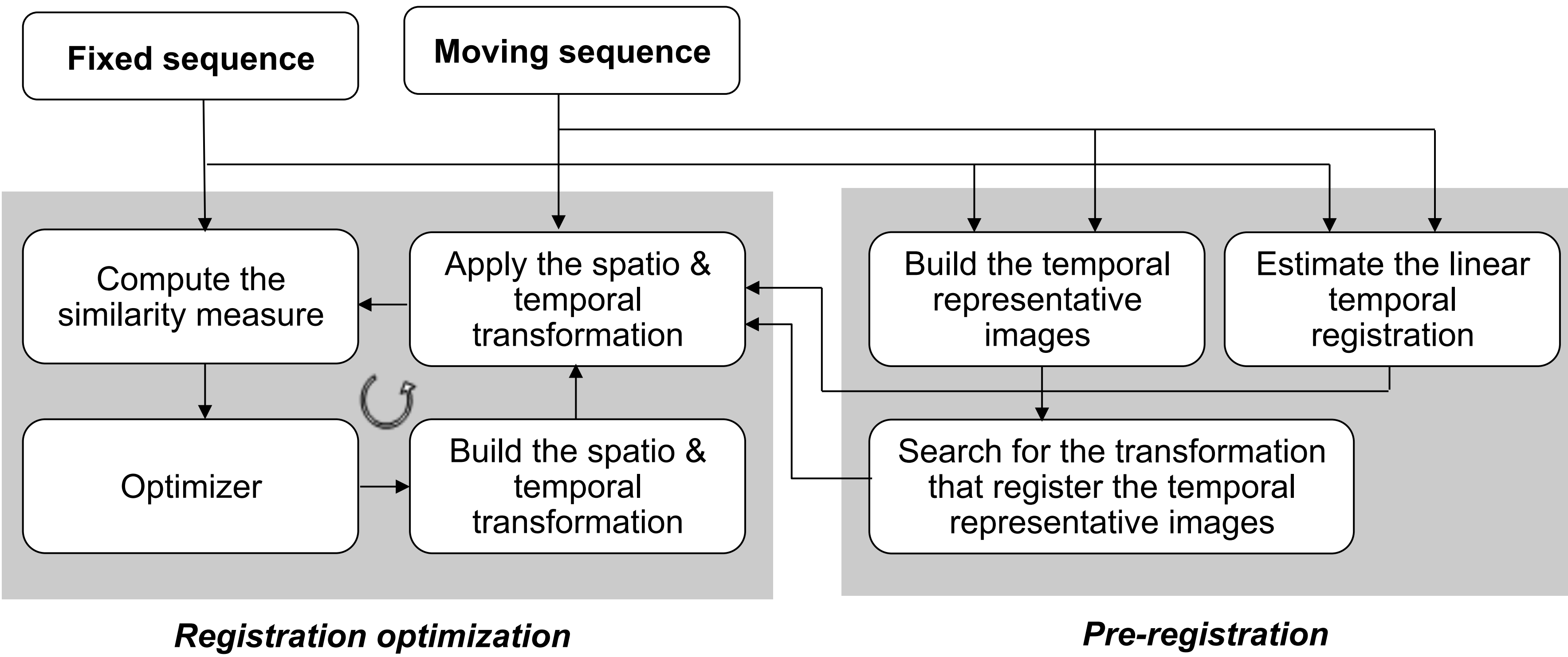
Registration **based on Iterative Optimization**

To speedup the computational process, a **multi-resolution strategy is frequently used**



Methods: Spatio & Temporal Registration

Spatio & Temporal registration based on Iterative Optimization

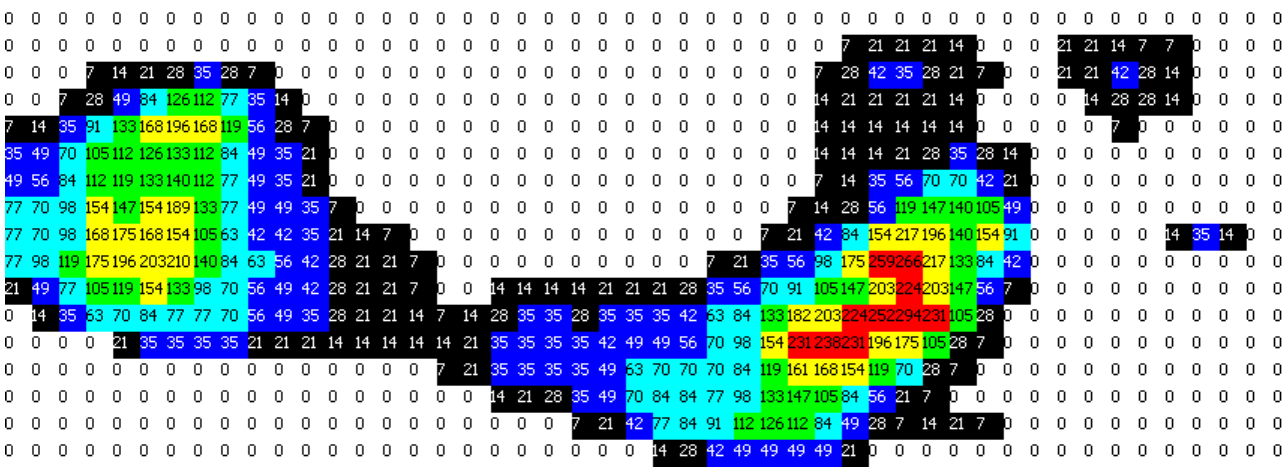


Oliveira, Sousa, Santos, Tavares (2011) Medical & Biological Engineering & Computing 49(7):843-850
Oliveira & Tavares (2013) Medical & Biological Engineering & Computing 51(3):267-276

Applications and Results: Plantar Pressure Images

Plantar Pressure Images

A **plantar pressure image** is a data set that **conveys the interaction between the foot sole and the ground**

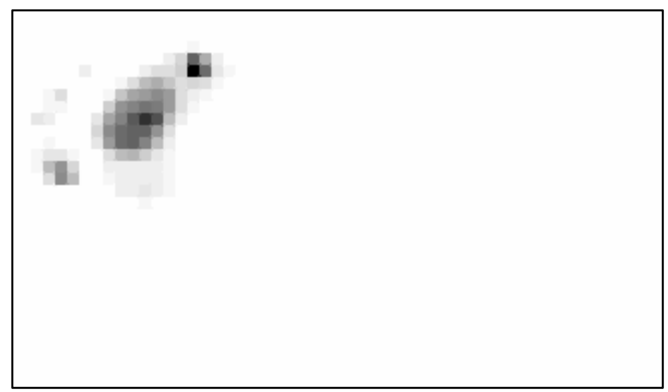


Static pressure images: from a plate with an array of piezoelectric sensors (left) and from a light reflection device (right)

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:

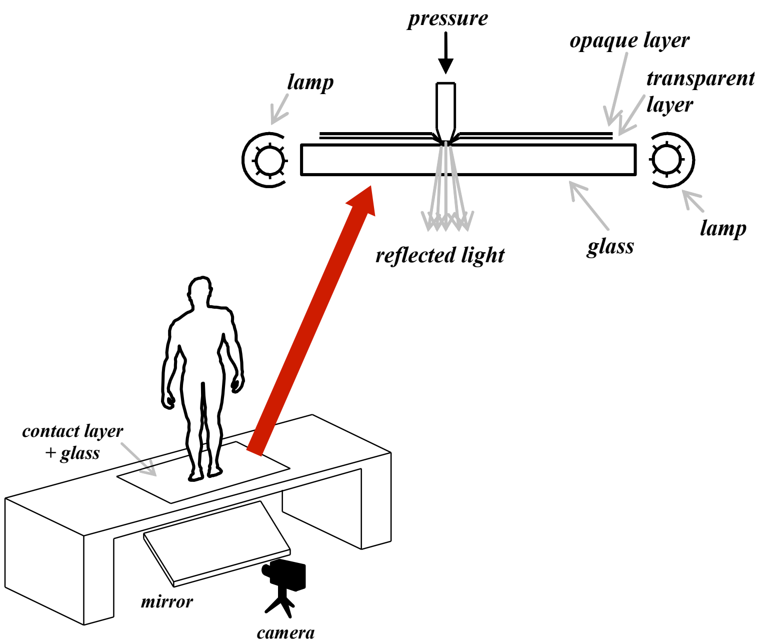


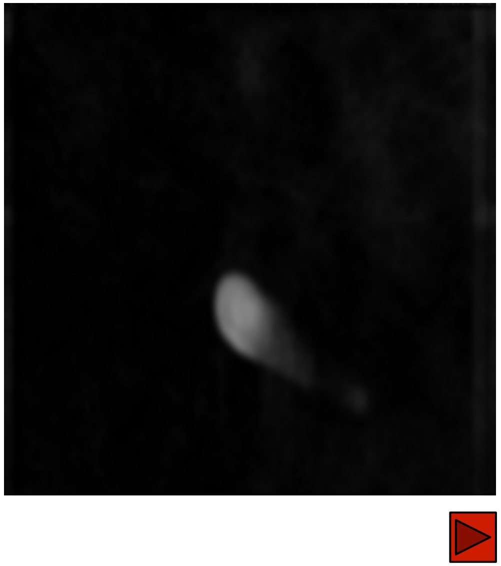
An EMED® plate and an example of an image sequence acquired

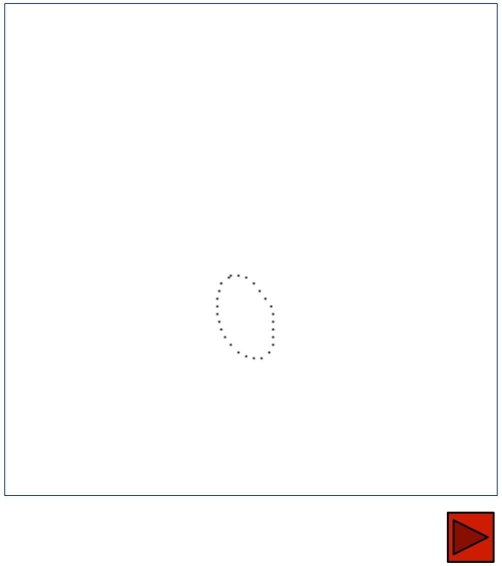
Plantar Pressure Images

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

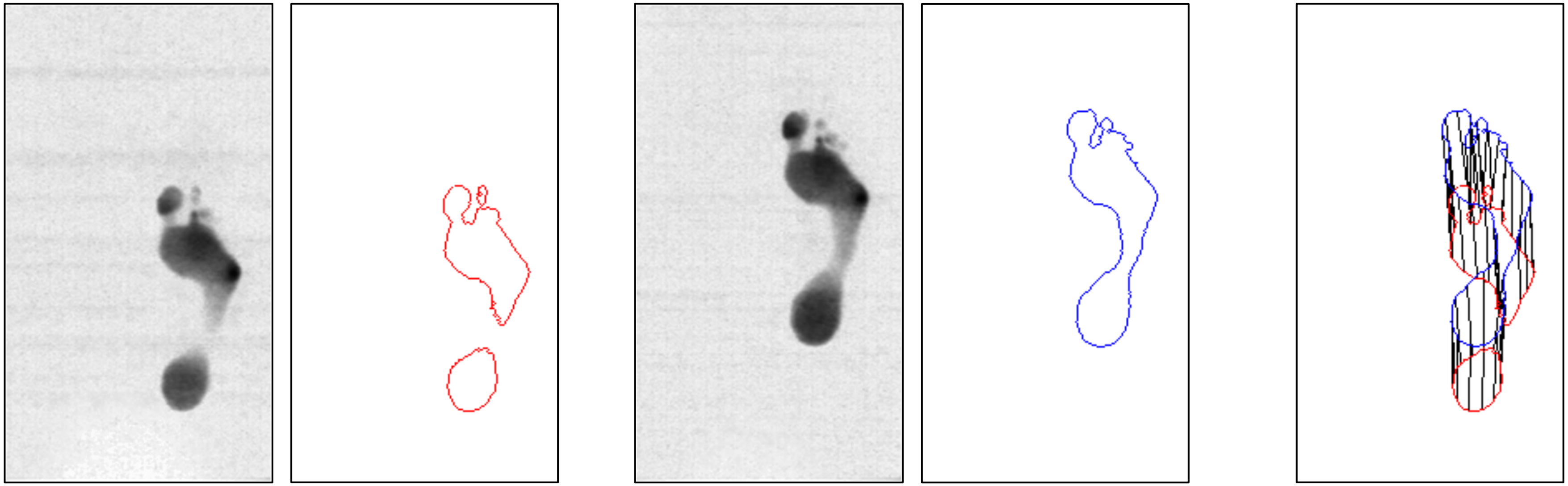
Registration **based on Contours Matching**

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**

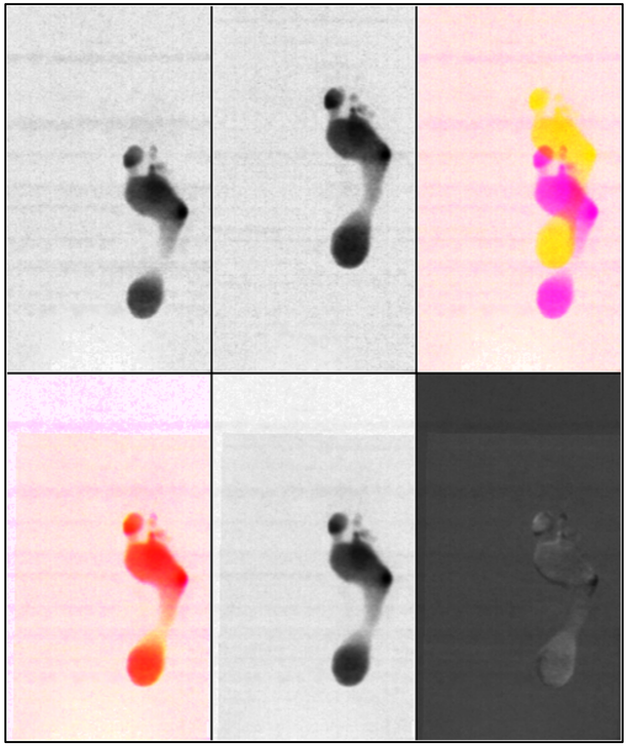
… cont.

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

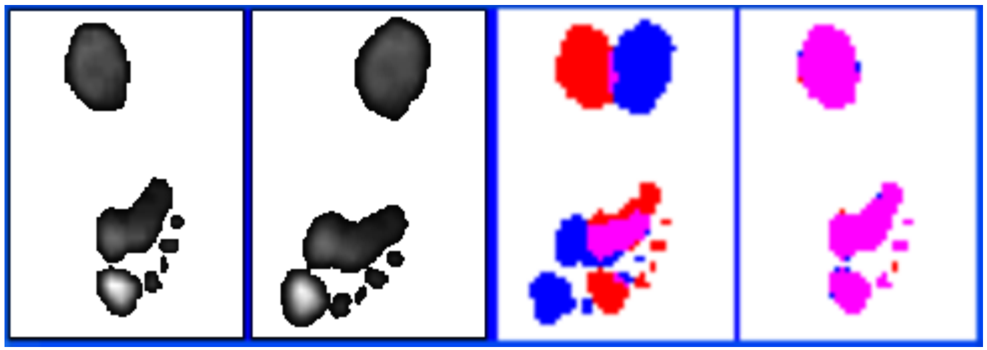


Registration **based on Direct Maximization of the Cross-Correlation**

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

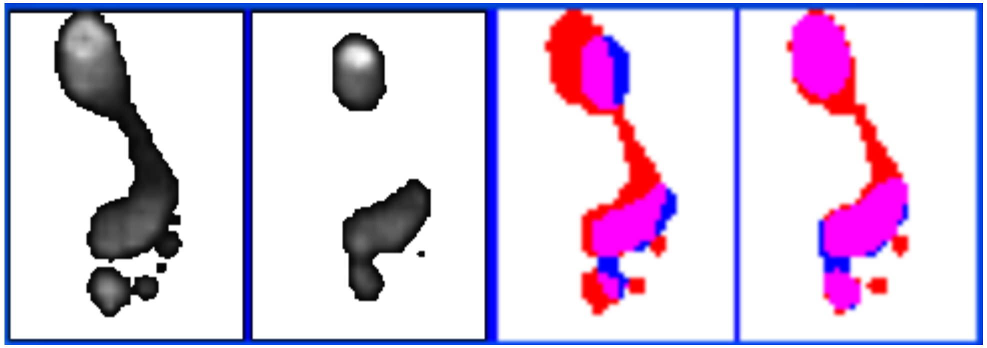
Processing time: 0.04 s (AMD Turion64, 2.0 GHz, 1.0 GB of RAM)

Images dimension: 45x63 pixels



Images from the same foot

Using a **rigid transformation**



Images from different subjects

Using a **similarity transformation**

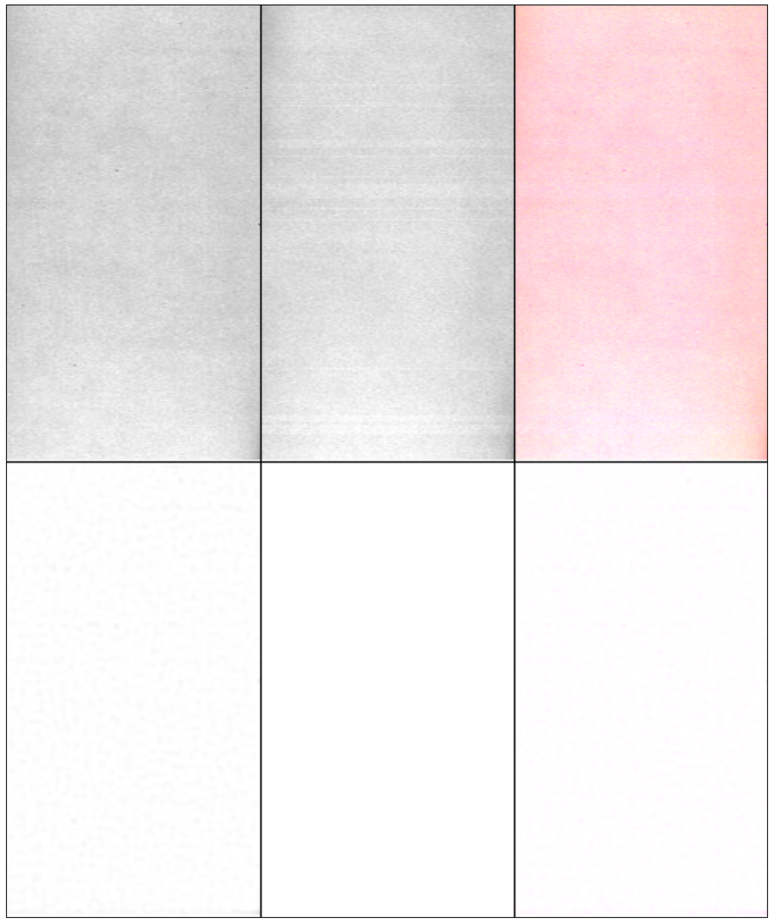
Spatio & Temporal registration of Plantar Pressure Image Sequences

Device: Light reflection (25 fps, resolution 30 pixels/cm^2)

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/cm^2, images dimension: 32x55x13; 32x55x18)

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

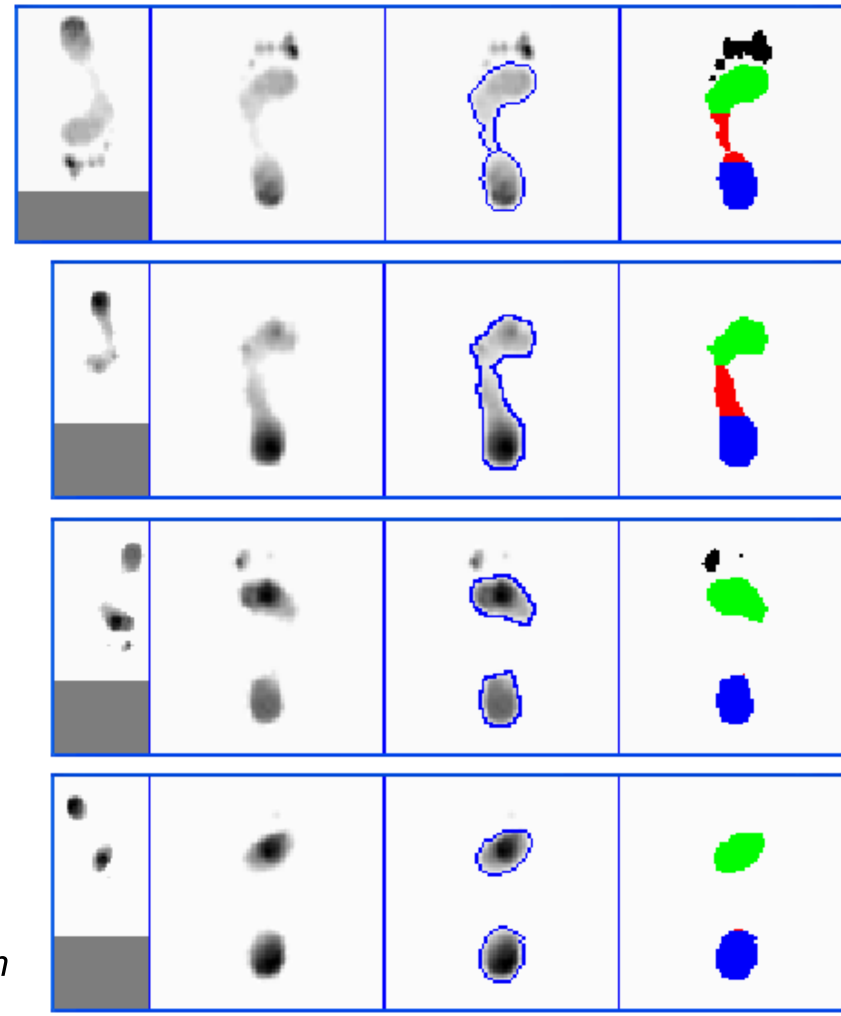
Processing time: 4 s - AMD Turion64, 2.0 GHz, 1.0 GB of RAM

	Fixed sequence	***Moving sequence***	***Overlapped sequences***
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



Oliveira, Sousa, Santos, Tavares (2012) Computer Methods in Biomechanics and Biomedical Engineering 15(11):1181-1188

Applications and Results: Medical Images

Registration **based on Contours Matching**

Fixed image and contour (MRI)

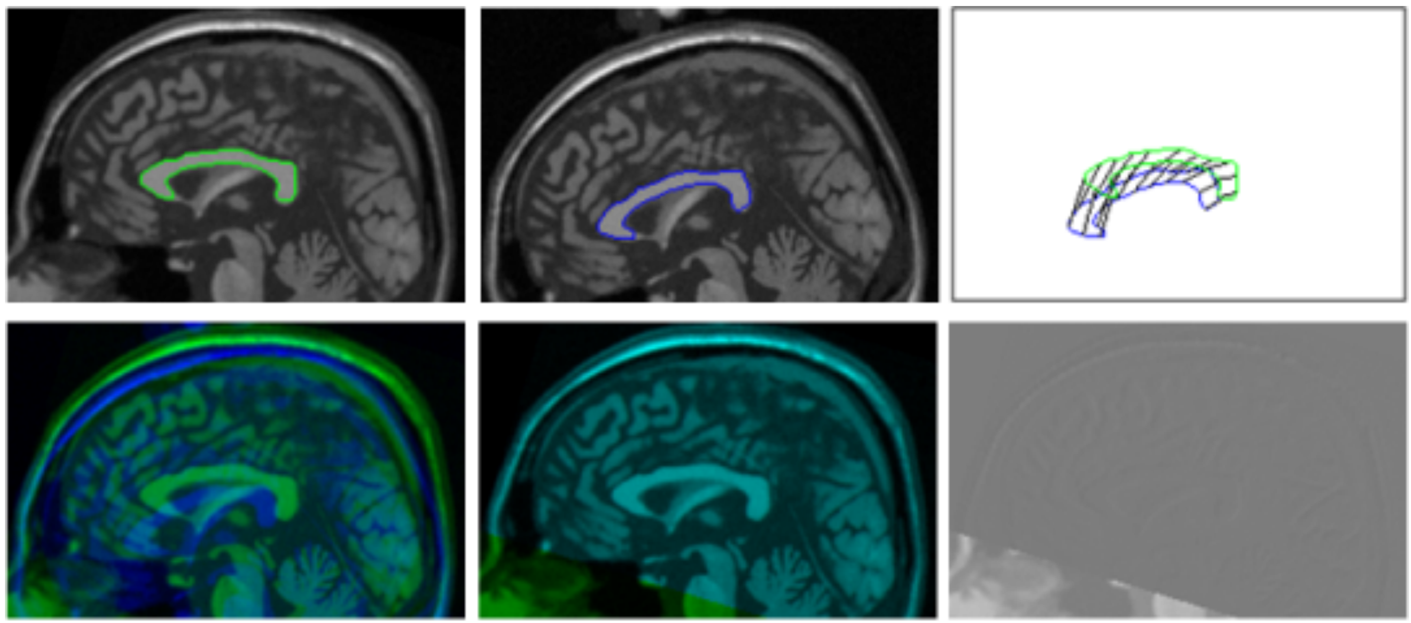
Moving image and contour (MRI)

Correspondences found between the Corpus Callosum contours

Registration: 2D, monomodal, intrasubject

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

Images dimension: 217x140 pixels



Overlapped images before the registration

Overlapped images after the registration

Difference between the images after the registration

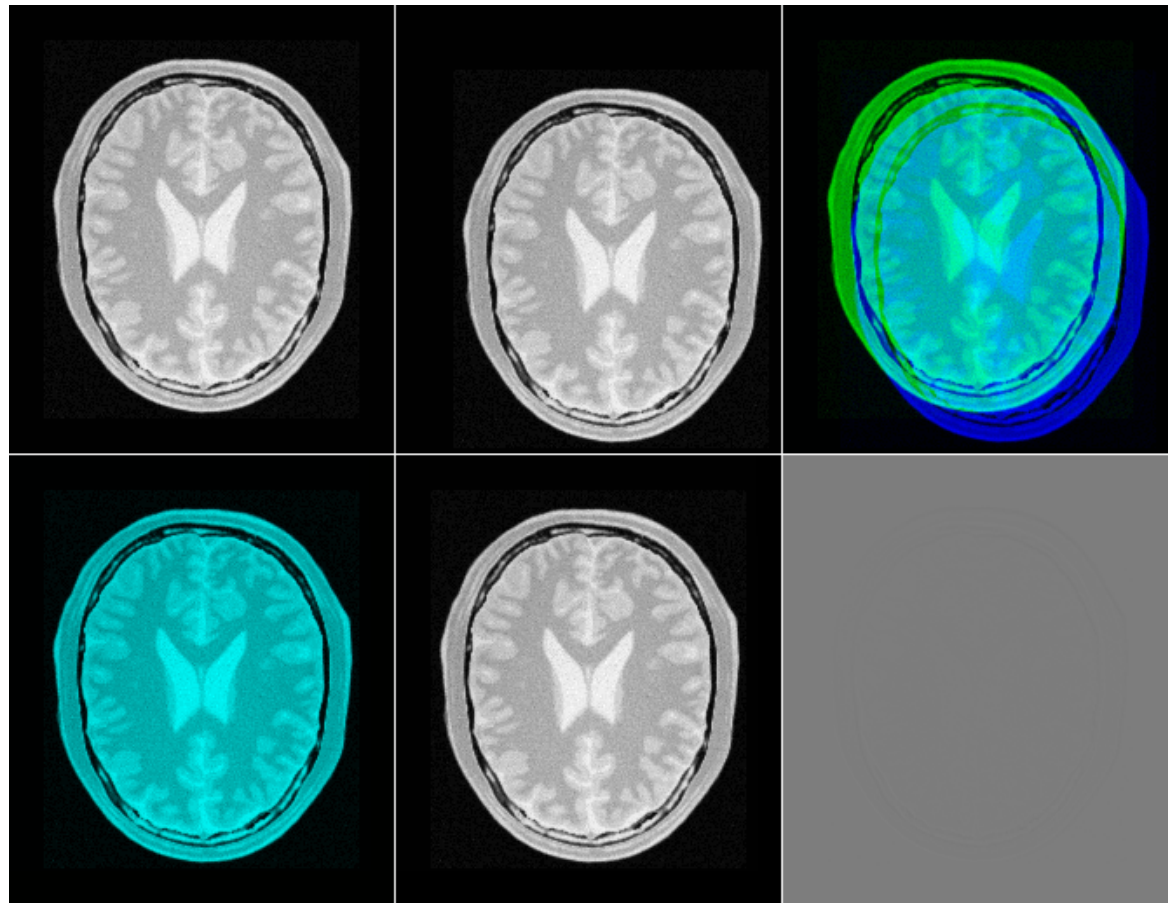
Oliveira & Tavares (2014) Computer Methods in Biomechanics and Biomedical Engineering 17(2):73-93

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



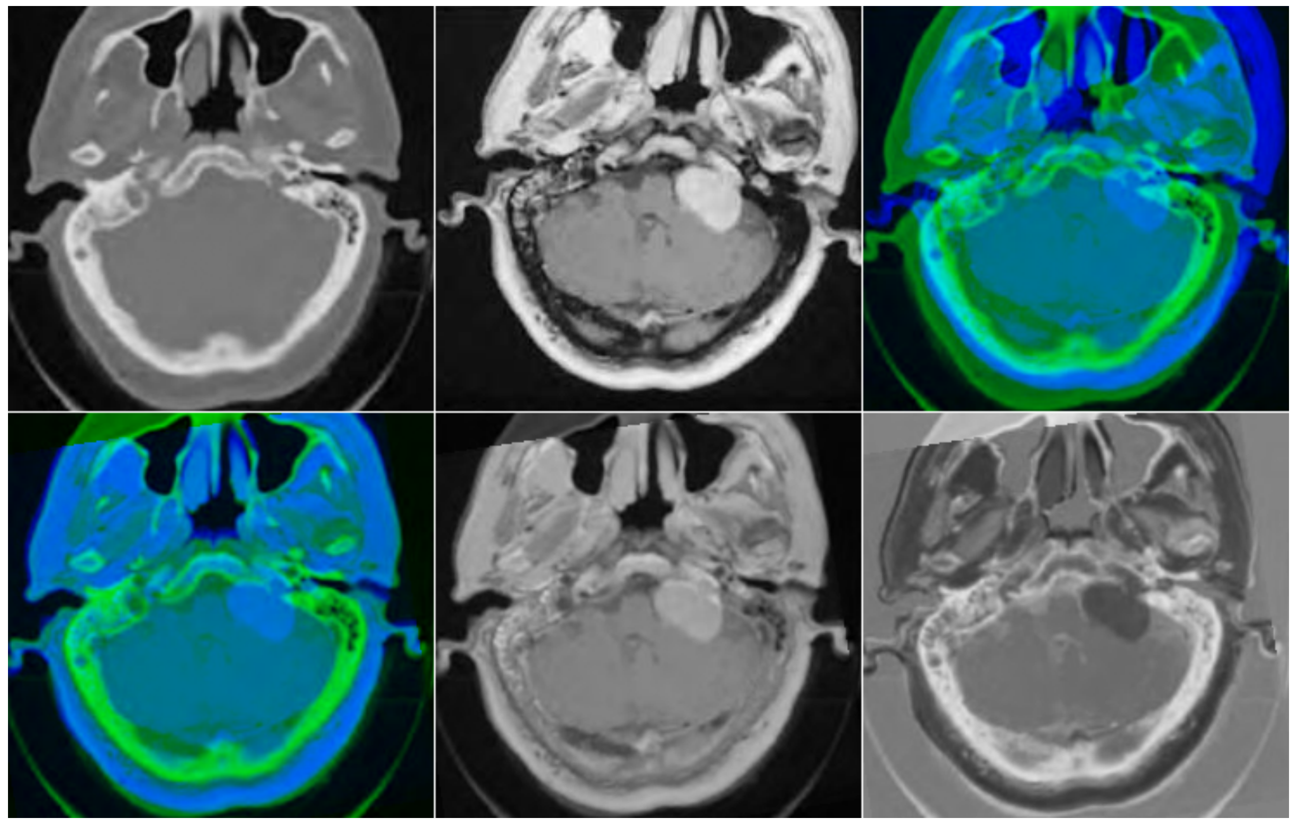
Registration **based on Iterative Optimization**

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)

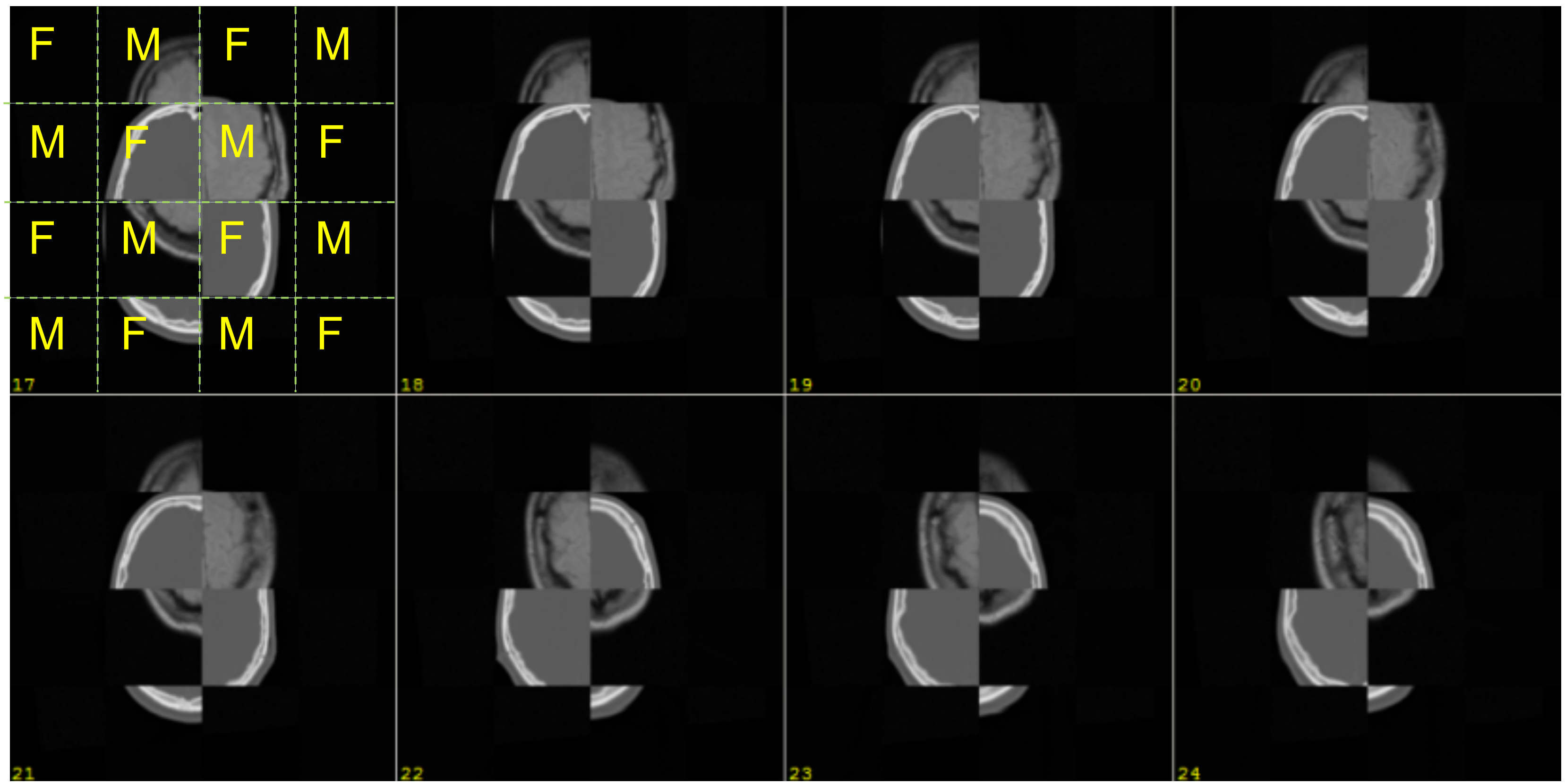
Images dimension: 246x234 pixels



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)

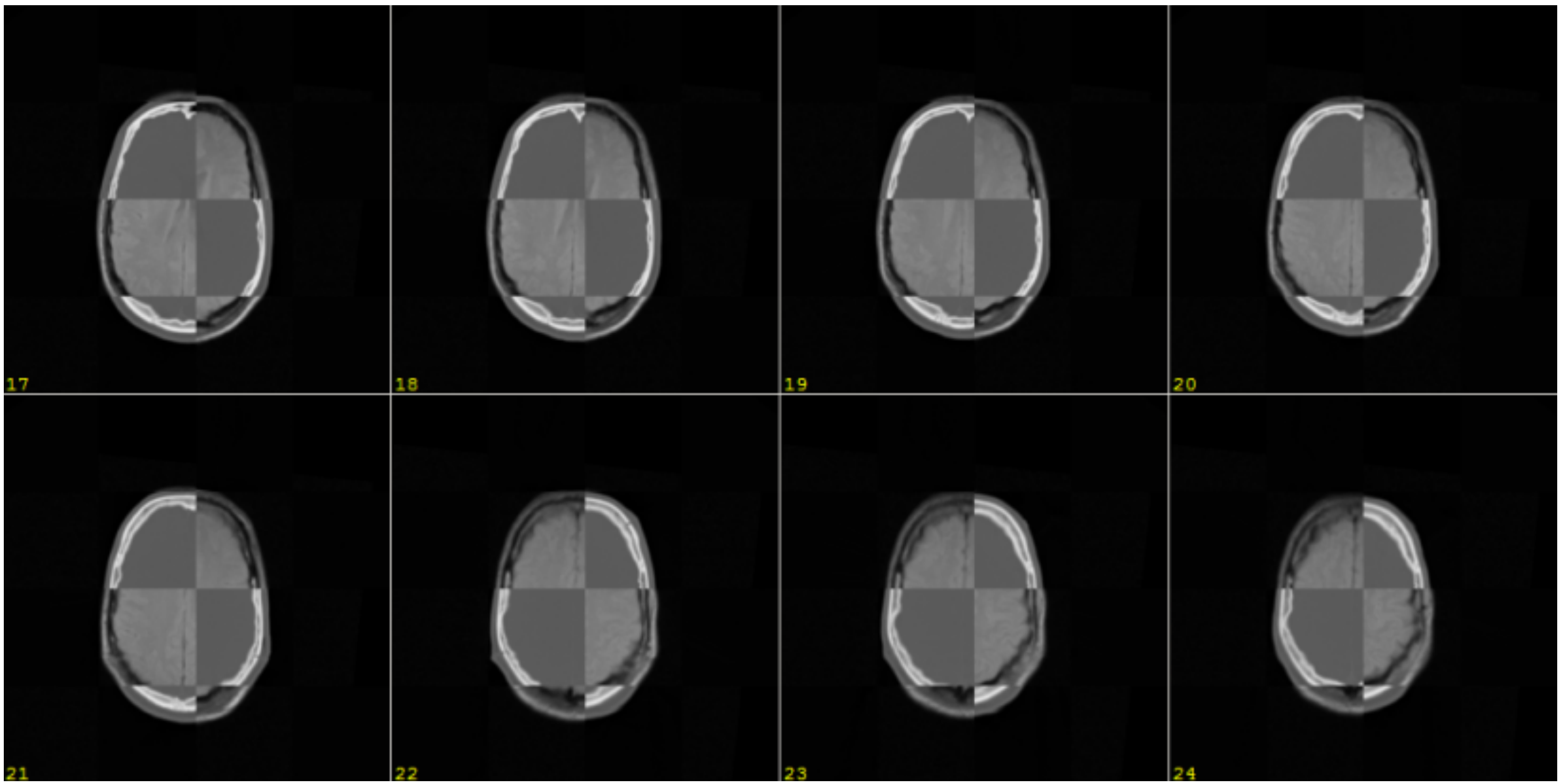


(The "checkerboard" slice is built by interchanging square patches of both slices and preserving their original spatial position in the fixed (F) and moving (M) slices)

Registration **based on Iterative Optimization**

… cont.

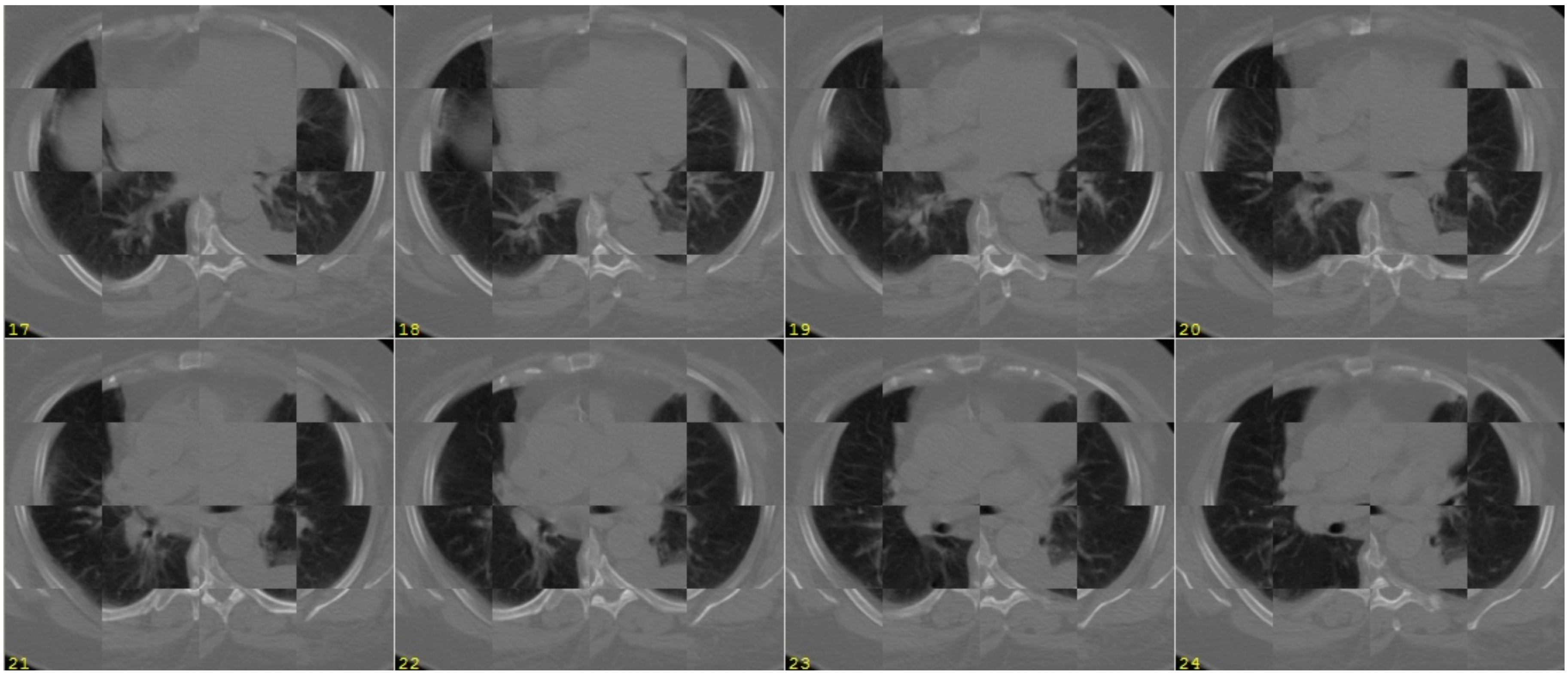
Checkerboard of the slices after the registration (CT/MRI-PD, brain)



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



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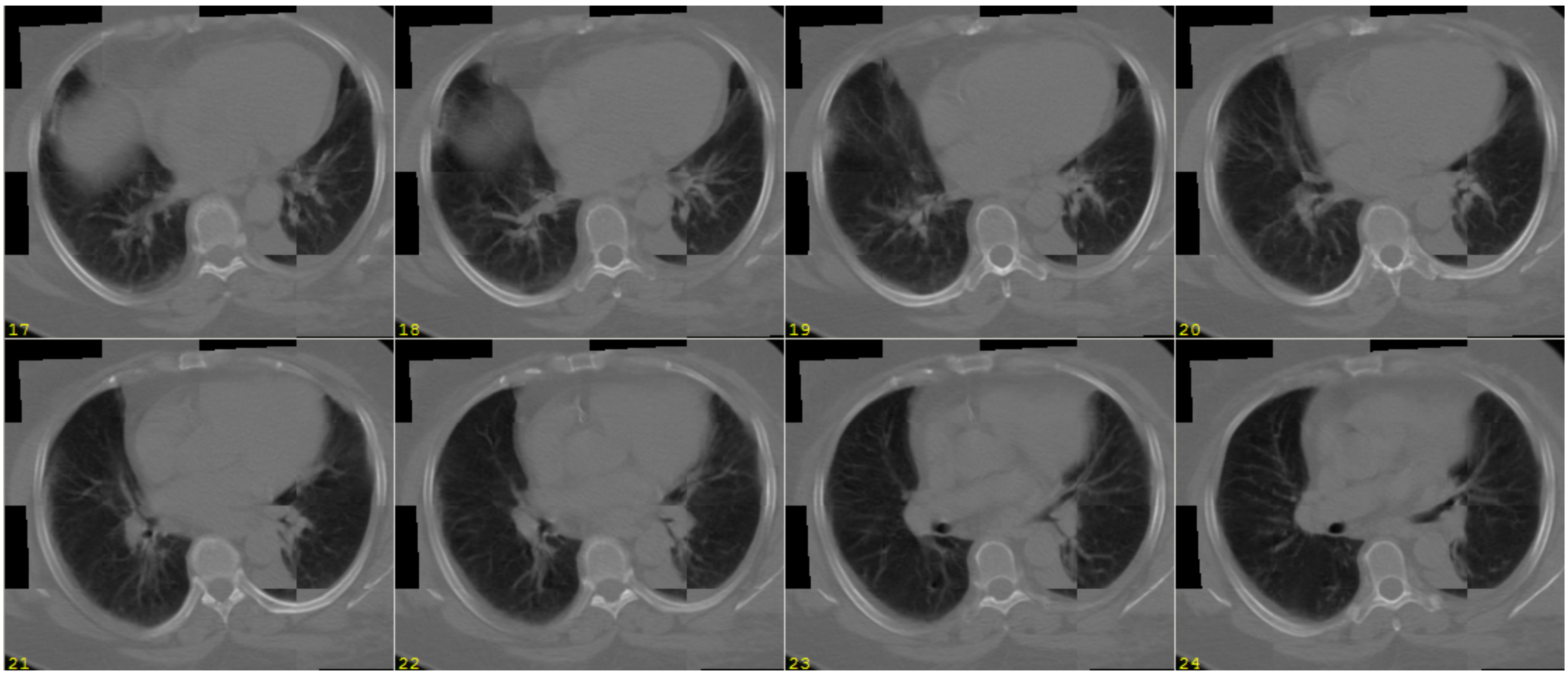
Registration **based on Iterative Optimization**

… cont.

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

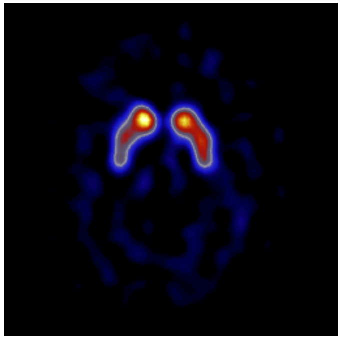


Registration: 3D, monomodal, intrasubject; Similatity measure: MI

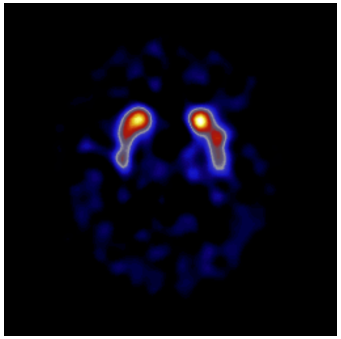
Application in Brain DaTSCAN SPECT images

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:

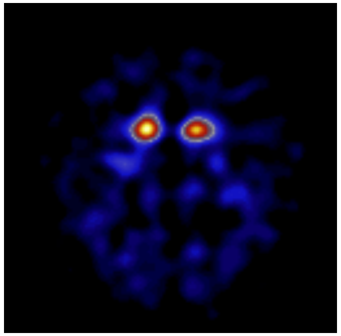
- Segment the relevant areas and perform dimensional analysis
- Quantify the binding potential of the basal ganglia
- Computation of statistical data relatively to a reference population
- Image classification for diagnosis purposes



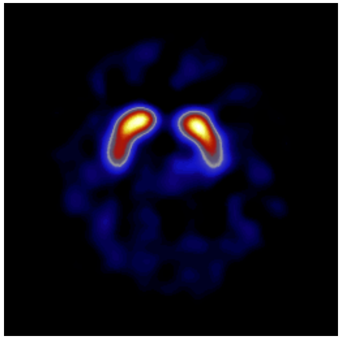
Normal



Alzheimer



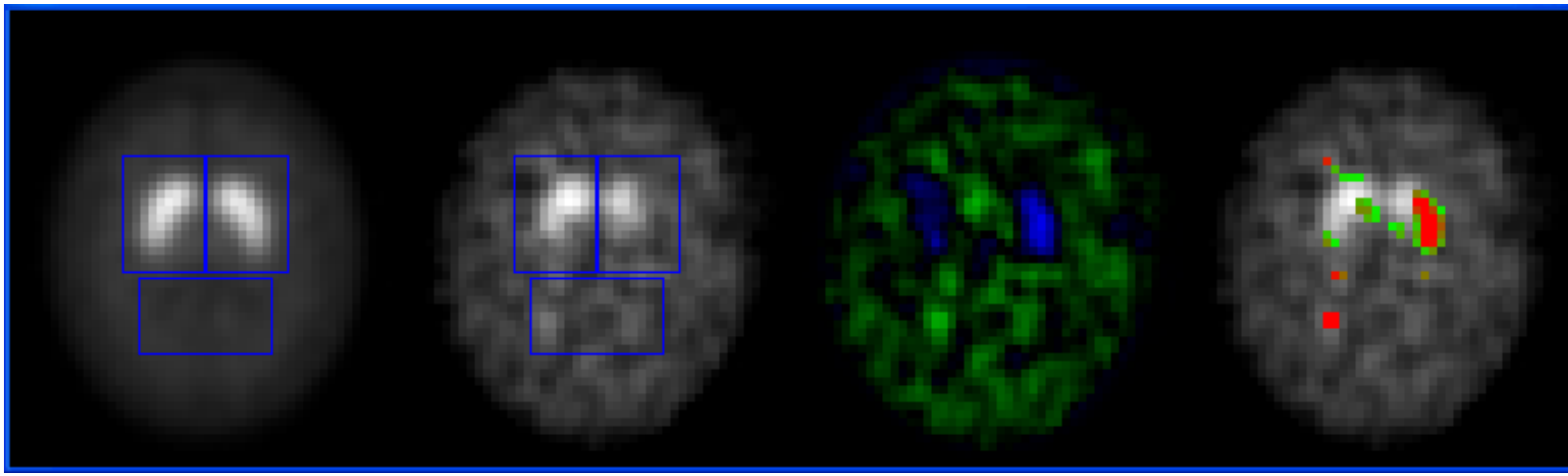
Idiopathic Parkinsonism



Essential tremor

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)*

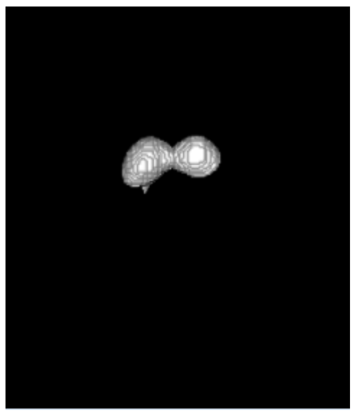
(The blue rectangles represent the 3D ROIs used to compute the binding potentials)

Oliveira et al. (2014) The Quarterly Journal of Nuclear Medicine and Molecular Imaging 58(1):74-84

Application in Brain DaTSCAN SPECT images

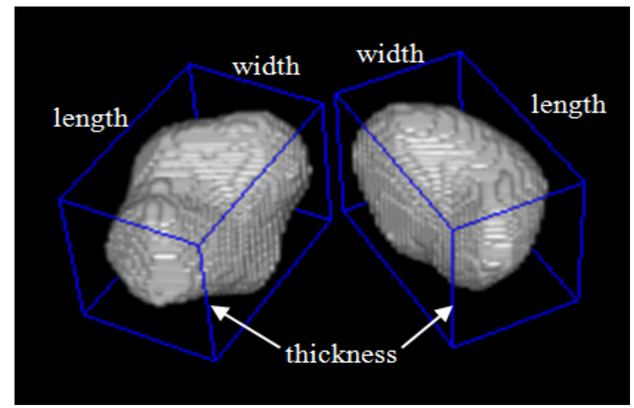
Basal ganglia 3D shape reconstruction and quantification

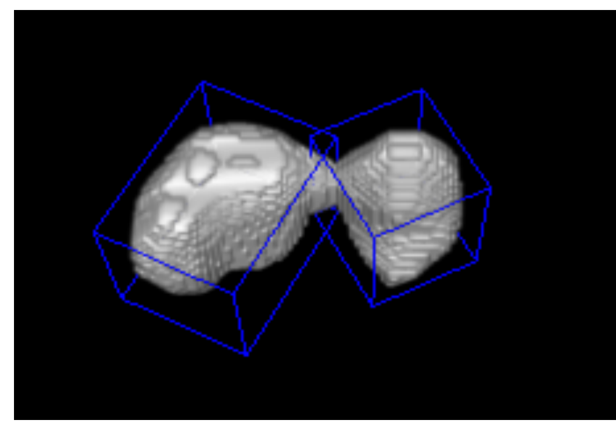
Basal ganglia from a mean image of a normal population



Basal ganglia from a patient with idiopathic Parkinson's disease

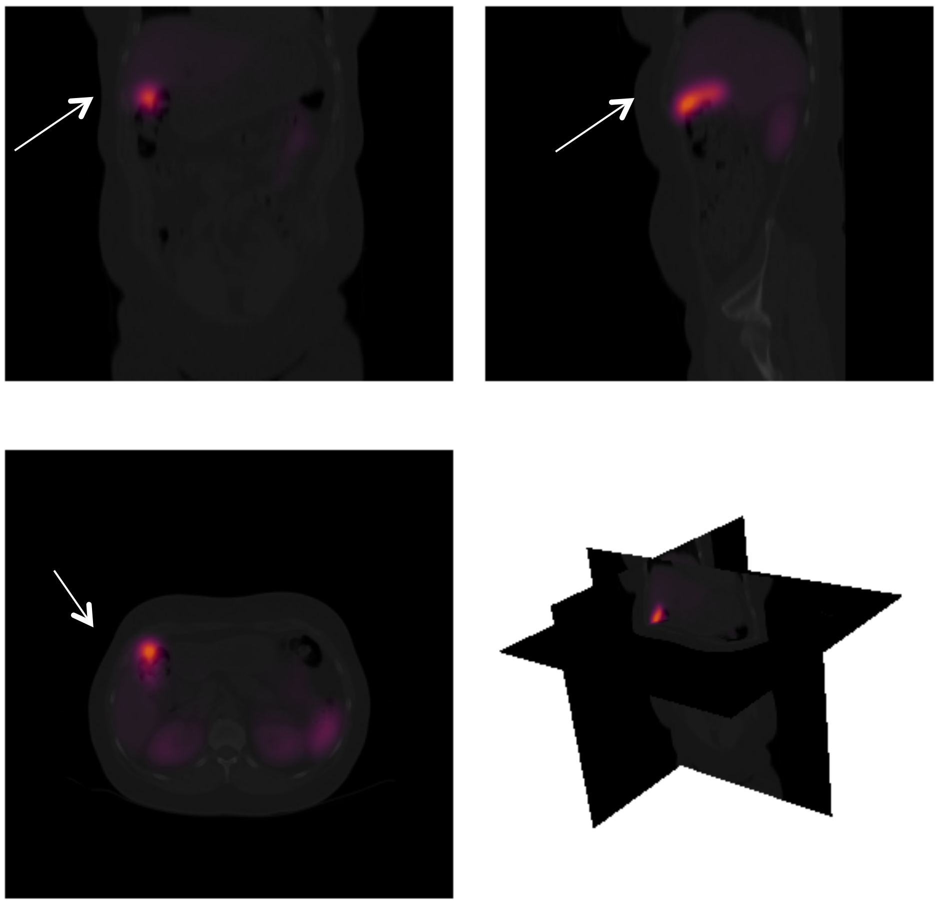
Basal ganglia from a patient with vascular Parkinson's disease



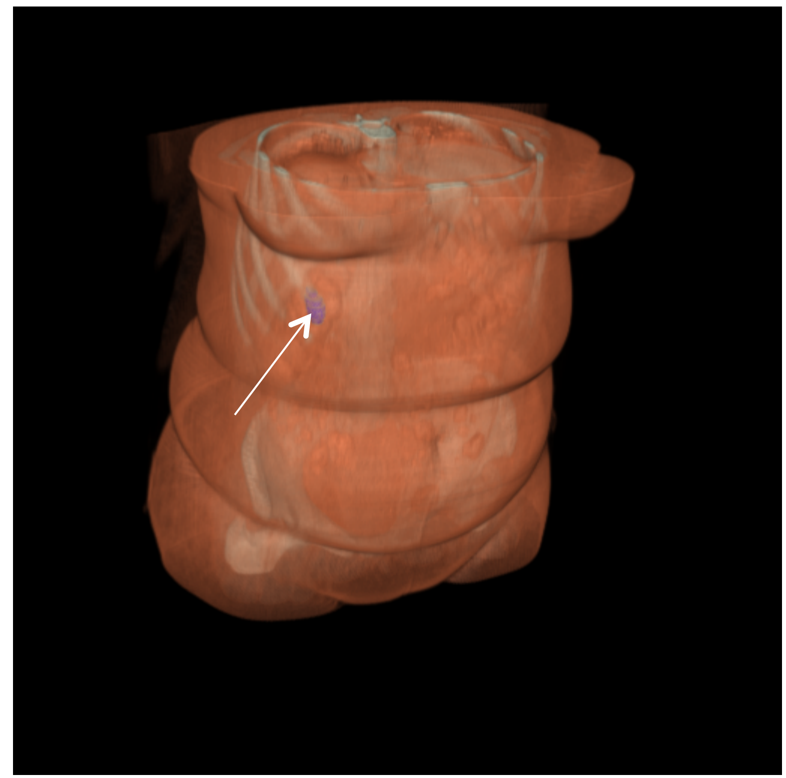


Oliveira et al. (2014) The Quarterly Journal of Nuclear Medicine and Molecular Imaging 58(1):74-84

Application in SPECT/CT registration and fusion



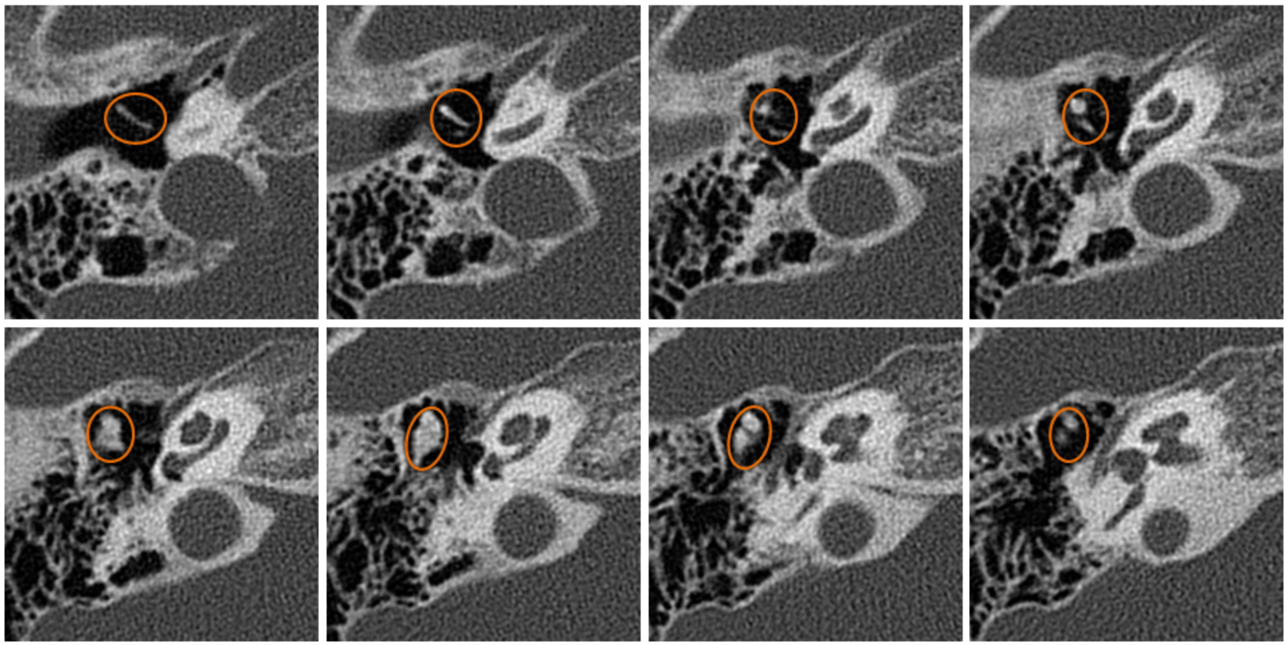
Three slices (coronal, sagittal and axial) after registration and identification of the potential lesion



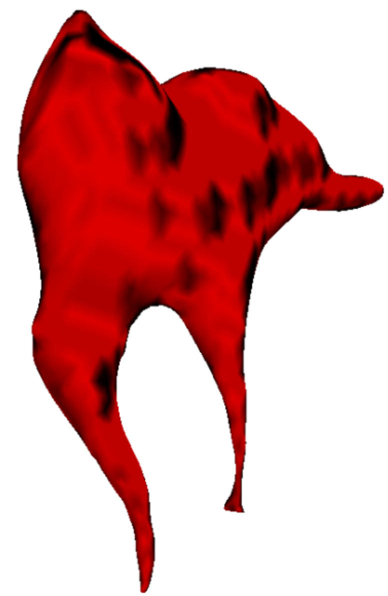
3D visualization after CT/SPECT fusion (the lesion identified in the SPECT slices is indicated)

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

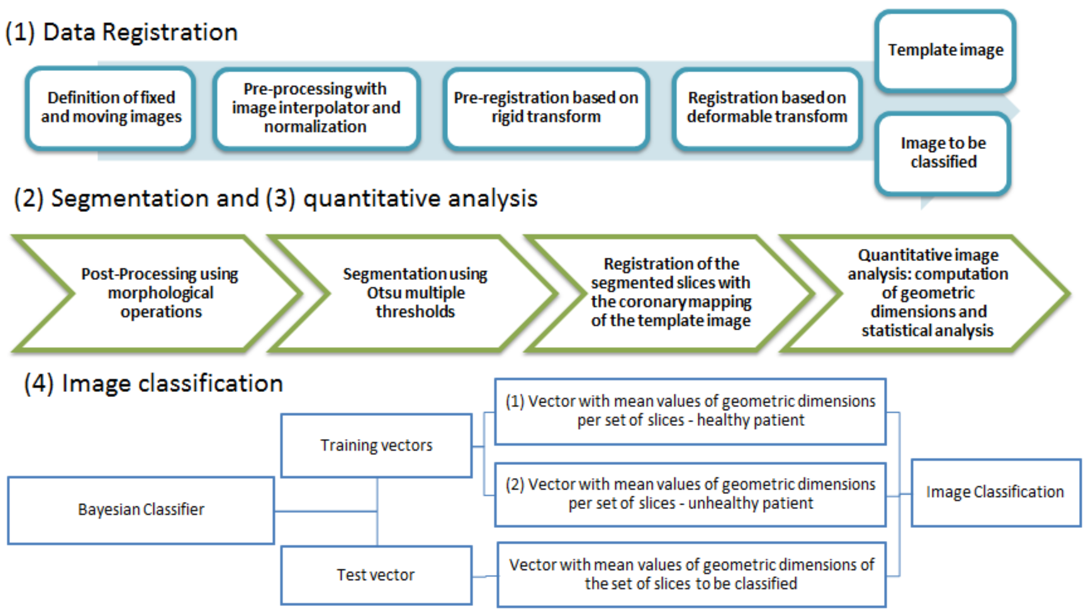


3D surface of the incus and malleus surface built

Oliveira, Faria, Tavares (2014) Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine 228(8):810-818, 2014

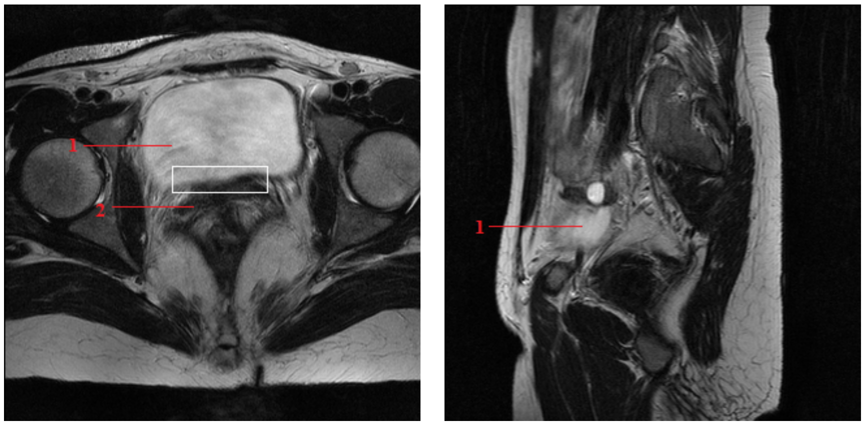
Application in Gated Myocardial Perfusion SPECT images

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

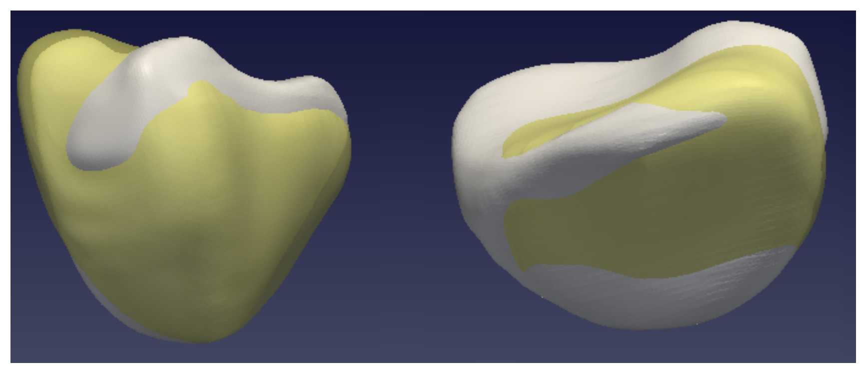


Template image (top), segmented image (bottom-left) and artery mapping (bottom-right)

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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- POSC/EEA-SRI/55386/2004

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Research Team (Computational Vision)

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  - In course: Zhen Ma, Simone Prado
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  - In course: João Nunes, Alex Araujo, Carlos Gulo, Roberta Oliveira, Danilo Jodas, Pedro Morais, Andre Pilastri, Nuno Sousa
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  - In course: André Silva, Silva Bessa, André Costa, João Ribeirinho, Frederico Junqueira, Ricardo Lé
- BSc students (2)
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Events & Publications

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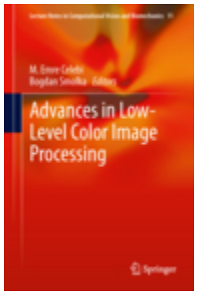
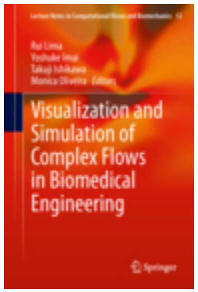
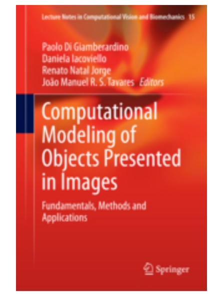
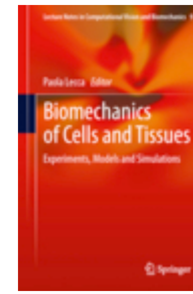
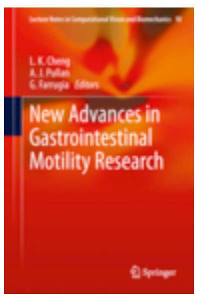
Lecture Notes in Computational Vision and Biomechanics (LNCV&B)
Series Editors: João Manuel R. S. Tavares, Renato Natal Jorge
ISSN: 2212-9391, Publisher: SPRINGER

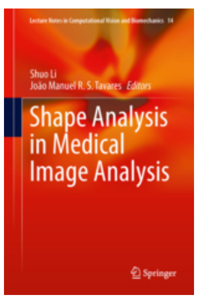


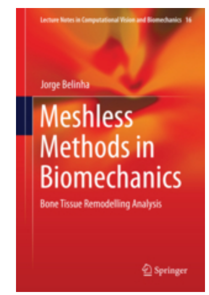


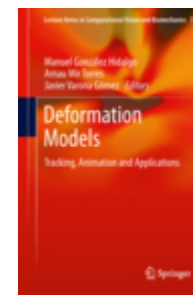


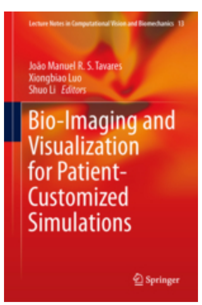


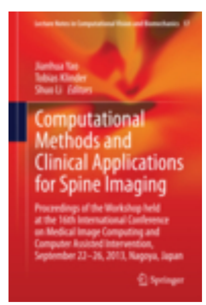












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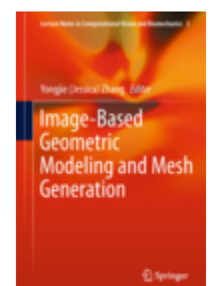

www.springer.com/series/8910

Events:

Mini-Symposium on
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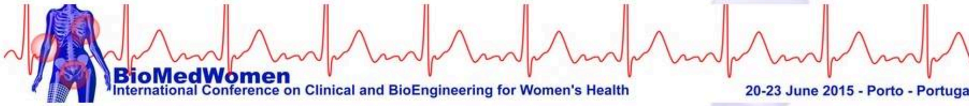

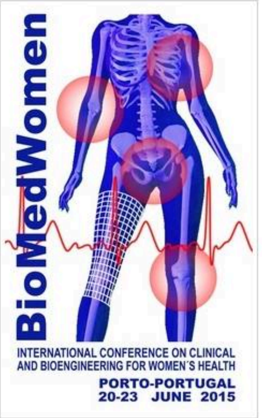

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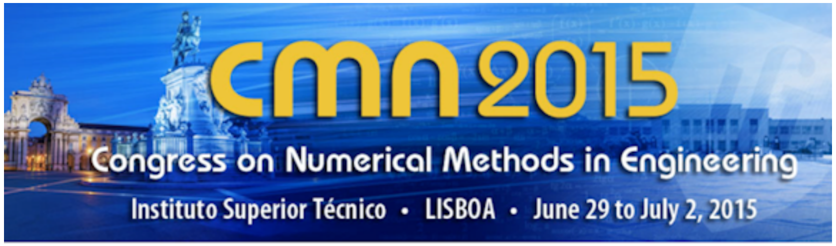
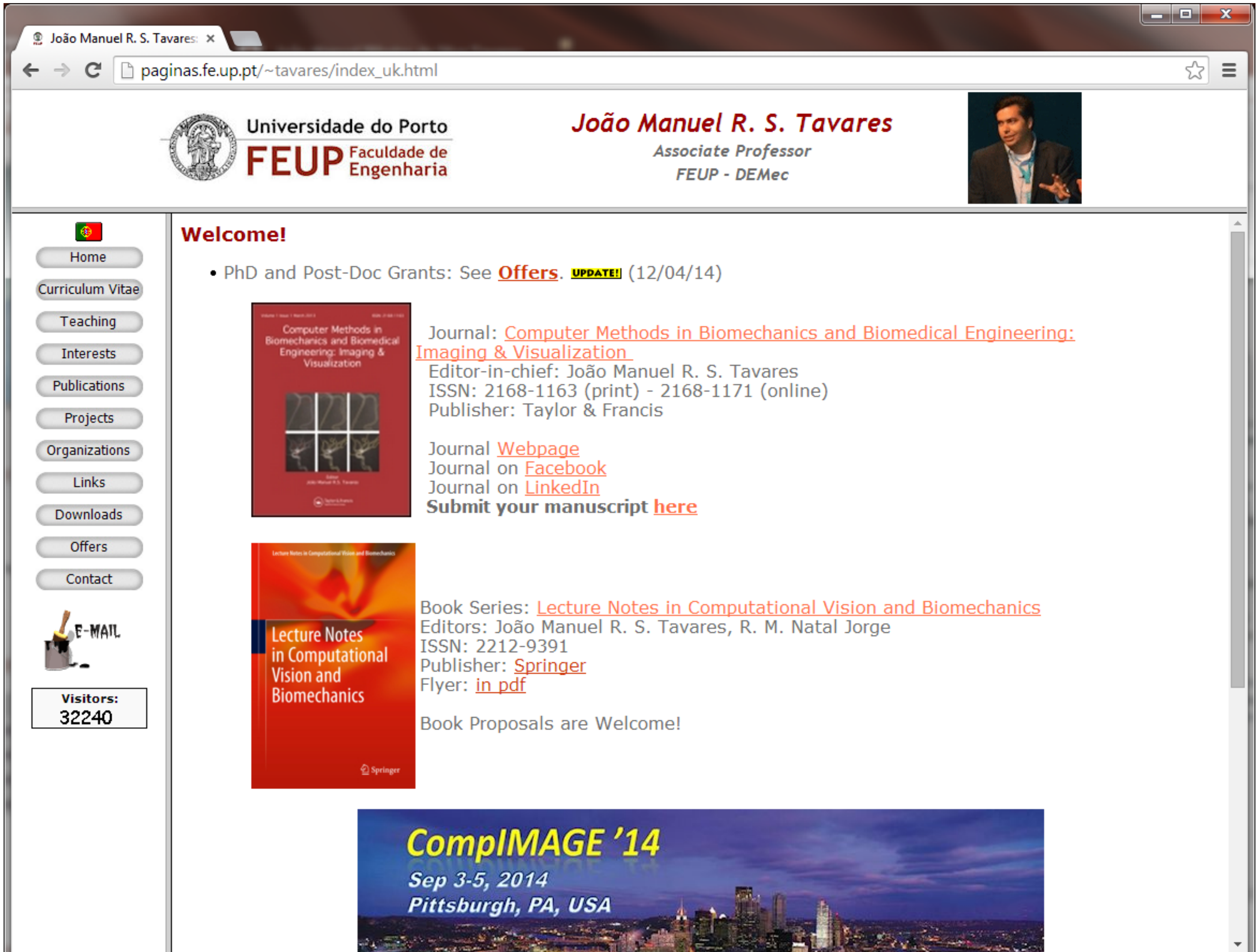


Thematic Session on
"Image Processing and Visualization"

Webpage (www.fe.up.pt/~tavares)



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Obrigado!

Analysis of Medical Images based on Computational Methods of Image Registration

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