Anisotropic diffusion for MRI segmentation and 2D/3D radiographic registration

Taha Jerbi

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Previous Team, Telecom Bretagne

- ITI (Image and Information processing) Dept
  - **Communication and Cognition**, which is concerned with modeling language and its cognitive links with images.
  - **Information Technologies for the Environment and Defense**, which groups activities linked principally with the use of satellite or airborne sensors and radars.
  - **Image and Information processing for Health**

Instituts thématiques Inserm

Institut national de la santé et de la recherche médicale

CHU BREST

L@TIM

Previous Team, LaTIM laboratory

integrated and pluridisciplinary research, associating doctors and scientists:

- Quantitative Multimodal Imaging for Diagnosis and Therapy
- Multimedia Medical Information Indexing, Tracking and Integrity.
- Computer Assisted Surgery for Orthopedics

I worked specially with: Valérie Burdin, Eric Stindel, and Christian Roux.

Outline

- **Anisotropic diffusion for the MRI segmentation**
- 2D/3D registration of EOS images
- Optic, infra-red and 3D ToF images for the study of the maize plant.

Anisotropic diffusion for the MRI segmentation

Aim: We use an anisotropic diffusion in a level set framework for low-level segmentation of necrotic femoral heads.

Main paper:

Taha Jerbi, Valérie Burdin, Faouzi Ghorbel and Jean José Jacq, « Modified data fidelity speed in anisotropic diffusion », 29th Annual International Conference of IEEE Engineering in Medicine and Biology society (EMBC07), Lyon France, August 2007.

Period: M.Sc. Thesis

Anisotropic diffusion for the MRI segmentation of necrotic femur

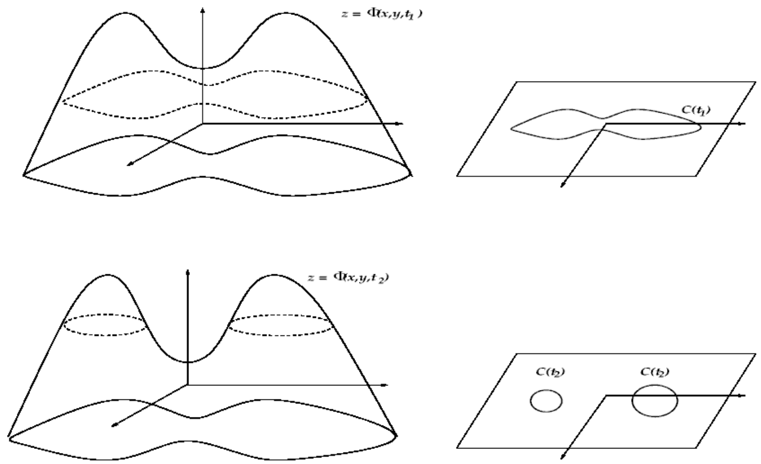
- Non invasive MR acquisition
- MRI acquisitions more adapted to the soft tissues than to bone structure
  - Noise
  - Edge

P. Perona, J. Malik « Scale-space and edge detection using anisotropic diffusion » IEEE Trans PAMI, 12 (1990), pp. 629–639

$$\frac{\partial I_t}{\partial t} = div\left[g\left(\left\|\vec{\nabla} I\right\|\right)\vec{\nabla} I\right]$$

Segmentation level set

S. Osher and J. A. Sethian, Fronts propagating with curvature dependent speed: Algorithms based on Hamilton-Jacobi Formulations, Journal of Computational Physics, volume 79, pp. 12-49, 1988.



$$C(p,t) = \{(x,y) : \varphi(x,y,t) = 0\}\ ,\ C(t) = \varphi^{-1}(0)$$

$$C(p,0) = \{(x,y) : \varphi(x,y,0) = 0\}$$

$$\varphi_t + F\left|\vec{\nabla}\varphi\right| = 0$$

Formulation advantages:

- follows easily the change on topology
- Implicit model: independent from parameterization
- No shape restriction
- The evolution is a differential expression invariant to orthogonal group transformations

Example 1 2 3

Anisotropic diffusion: formulation with level-sets

PDE +MED estimator

$$\begin{cases} I_{t=0} = I_0 \\ \hat{\sigma}_t = (1.4826\, M_{u\in D_I}(|\vec{\nabla} I_{t,u}|) \\ \dfrac{\partial I_t}{\partial t} = -\alpha H(I_t) g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t)|\vec{\nabla} I_t| + \beta \vec{\nabla} g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t) \cdot \vec{\nabla} I_t - \gamma (I_t - I_0)|\vec{\nabla} I_t| \end{cases}$$

Non linear diffusion term | Contrast enhancement term | Data fidelity term

Anisotropic diffusion for the MRI segmentation

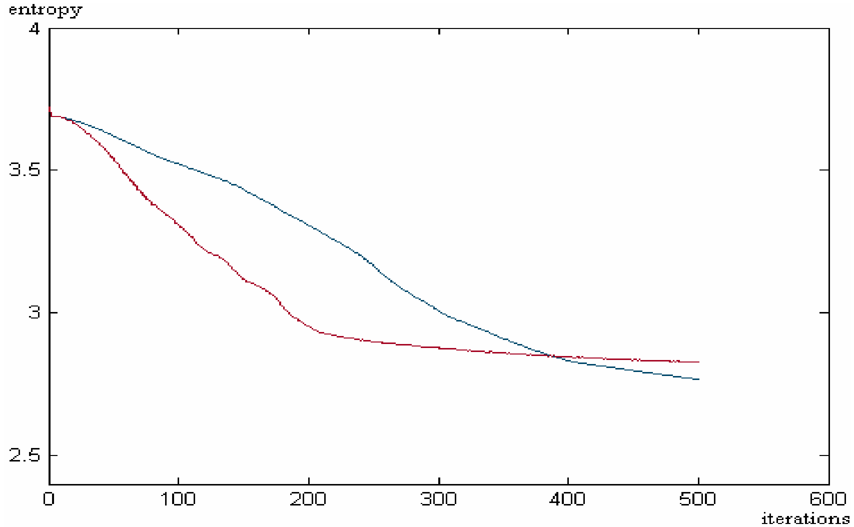
Using entropy for evaluation

The better segmentation we have, the more homogenous the results are, and the lower the entropy is.

$$E(I) = \sum_{j=1}^{N} \frac{V_j}{V_I} E(R_j)$$

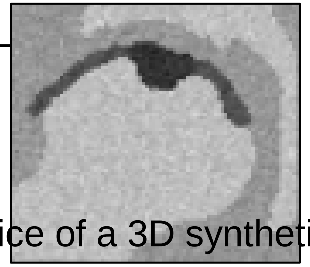
where

$$E(R_j) = -\sum_{m \in V_j^v} \frac{S_j(m)}{V_j} \log \frac{S_j(m)}{V_j}$$



Entropy evaluation of diffusion with two different configurations

In the last iterations, classical data fidelity term penalizes the diffusion.



Slice of a 3D synthetic data

Using data fidelity speed

$\alpha = 1, \beta = 0, \gamma = 0.1$

Without data fidelity speed

$\alpha = 1, \beta = 0, \gamma = 0$

Anisotropic diffusion : Modification of the classical scheme

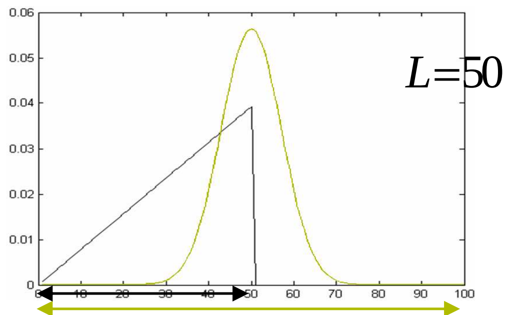
PDE +MED estimator

$$\begin{cases} I_{t=0} = I_0 \\ \hat{\sigma}_t = (1.4826\, M_{u \in D_I} (|\vec{\nabla} I_{t,u}|) \\ \dfrac{\partial I_t}{\partial t} = -\alpha H(I_t) g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t) |\vec{\nabla} I_t| + \beta \vec{\nabla} g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t) \cdot \vec{\nabla} I_t - \gamma (I_t - I_0) |\vec{\nabla} I_t| \end{cases}$$

Data fidelity speed modification

$$\frac{\partial I_t}{\partial t} = -\alpha H(I_t) g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t) |\vec{\nabla} I_t| + \beta \vec{\nabla} g(|\vec{\nabla}\tilde{I}_t|, \hat{\sigma}_t) \cdot \vec{\nabla} I_t - \gamma (I_t - I^*_{t-L}) |\vec{\nabla} I_t|$$

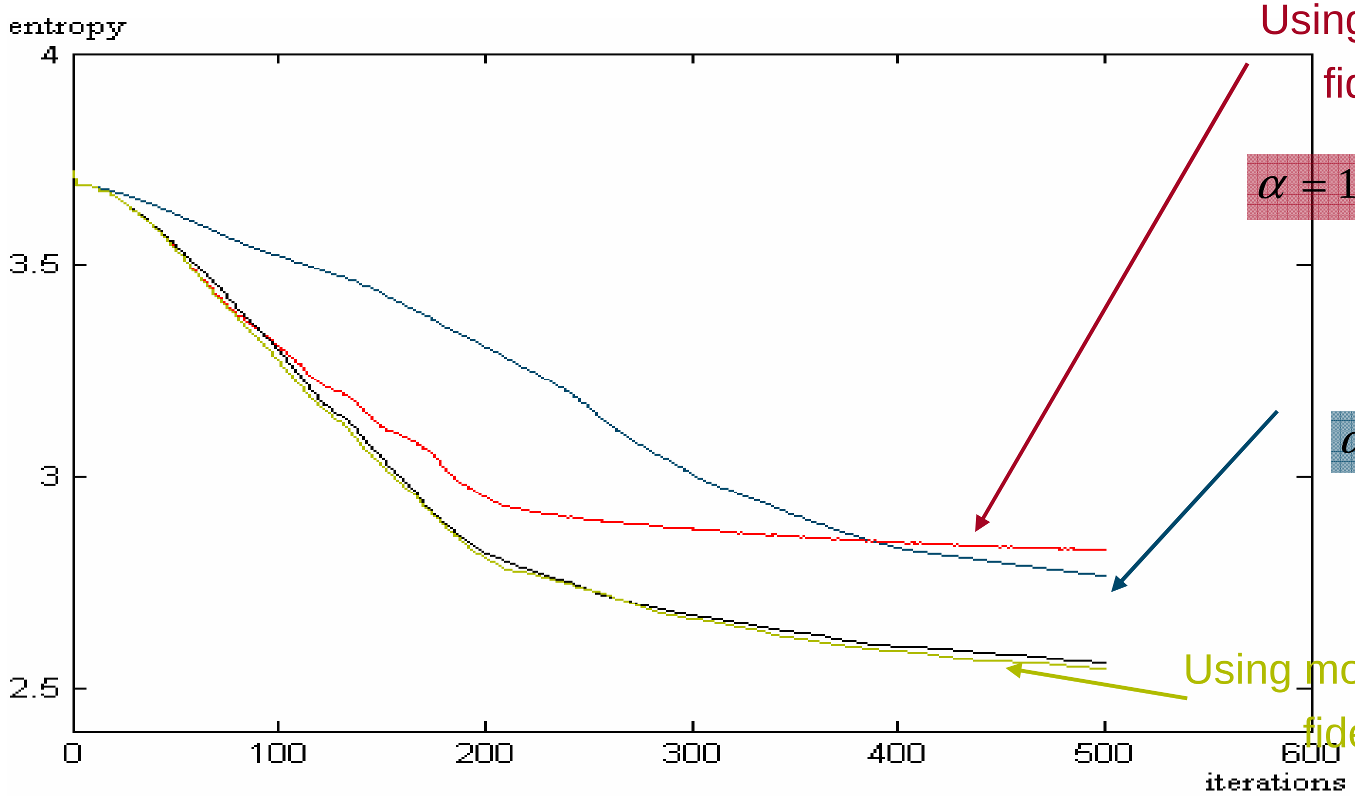
The construction of the referenced data with the time delay $\varphi = L_* \delta_t$ in the iteration n as:



Weights of the last results in the construction of referenced data

$$I^*_{n-L} = \frac{\sum_{i=1}^{N} h(i) I_{n-i}}{\sum_{i=1}^{N} h(i)}$$

Anisotropic diffusion: Evaluation on synthetic data



Using classical data fidelity speed

$\alpha = 1, \beta = 0, \gamma = 0.1$

Without data fidelity speed

$\alpha = 1, \beta = 0, \gamma = 0$

Using modification in data fidelity speed

$\alpha = 1, \beta = 0, \gamma = 0.1$

Evaluation of modified data fidelity term action

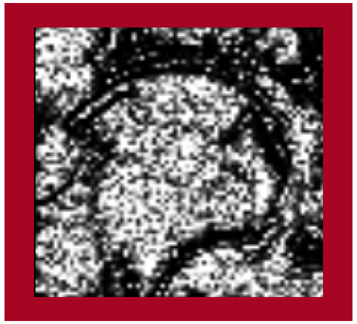
Anisotropic diffusion: evaluation on real data

- Results

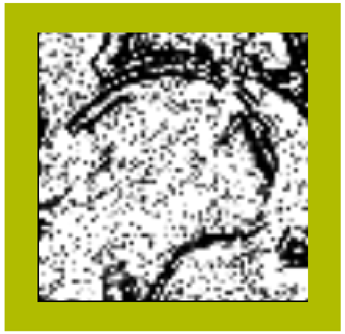
Initial real data slice

Result on real data slice without using the modification

Result on real data slice using the Gaussian modification



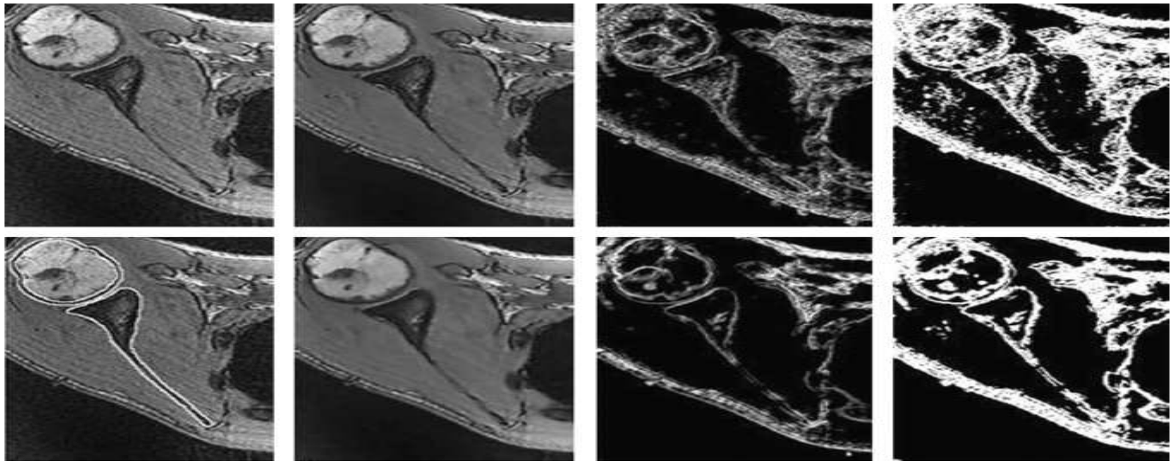
Differences between initial data and the results without modification



Differences between initial data and the results using the Gaussian modification

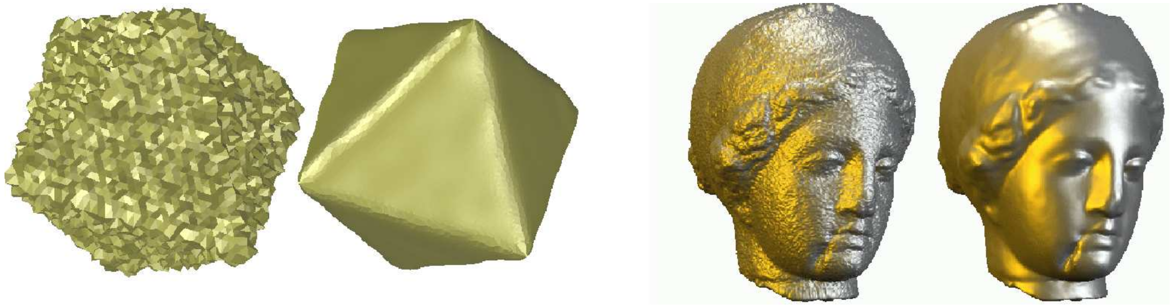
Anisotropic diffusion, continuation…

- This work continues in the same team with Refka Ragoubi thesis (defense next year).



« Pre-Processing of MRI volume using robust anisotropic filtering for shoulder segmentation » R. Ragoubi Hor, V. Burdin, T. Jerbi, O. Rémy-Néris, IRBM Vol 33, Issue 1, February 2012, pp 11–17

Anisotropic diffusion, results of other teams



T. Preuβer and M. Rumpf. A Level Set Method for Anisotropic Geometric Diffusion in 3D Image Processing, *SIAM J. Appl. Math., to appear, 2002*

Outline

- Anisotropic diffusion for the MRI segmentation
- **2D/3D registration of EOS images**
- Optic, infra-red and 3D ToF images for the study of the maize plant.

2D/3D registration of EOS images

Aim: Motion estimation of the lower limb bones using EOS acquisitions

Main paper

Taha Jerbi, Valérie Burdin, Julien Leboucher, Eric Stindel, Christian Roux, "2D-3D frequency registration using a low-dose radiographic system for knee motion estimation", IEEE TBME, 2012 Feb 22.

Period: PhD thesis

2D/3D registration of EOS images

- Interest
  - Study of the ligament laxity for the knee joint

    France: 40.000, US: 277.000 (prostheses/year).
  - Interest for the hip joint

    France: 120.000, US: 193.000 (prostheses/year).

2D/3D registration of EOS images

- Bones motion estimation of the knee joint

Invasivity, Precision
Physiological study,
….

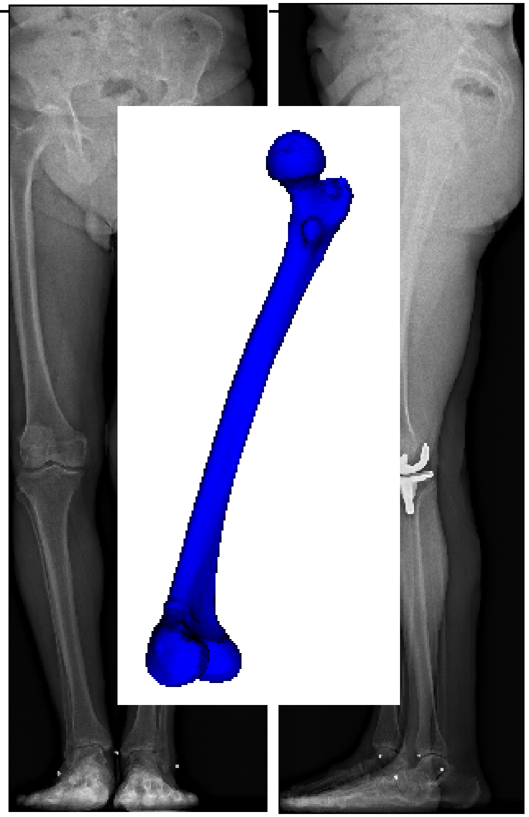
Medical Imaging:
CT, MRI, …

2D/3D registration of EOS images

EOS system presentation

- G. Charpak Detectors (Nobel price 1992)
- Two simultaneous radiographs front and profile
- Weight bearing position
- Low dose radiation
- 3D reconstruction possibility (LBM ENSAM Paris,

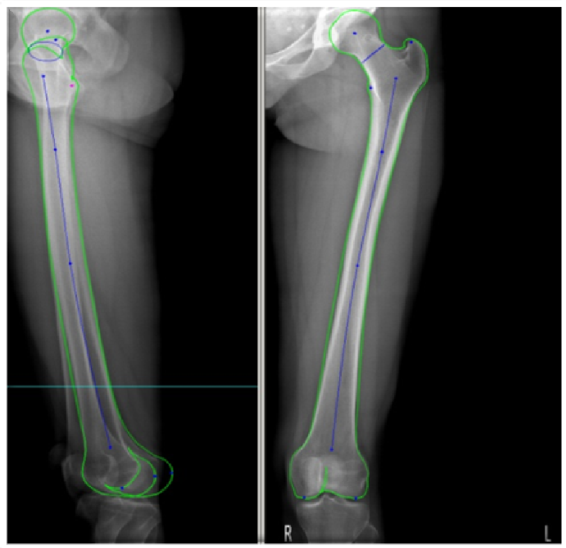
LIO Ecole de Technologie Supérieure Montréal)



2D/3D registration of EOS images

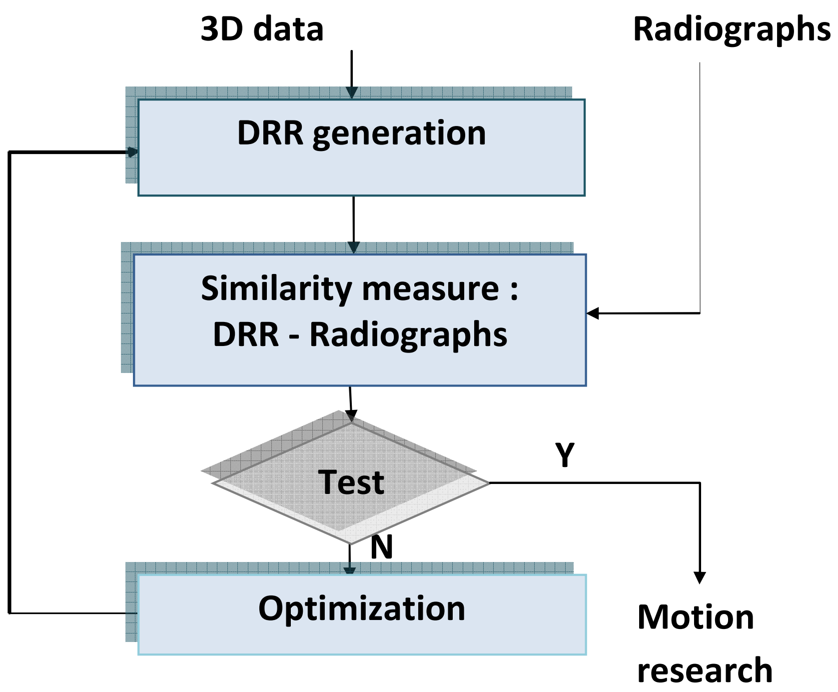
EOS Imaging specificities

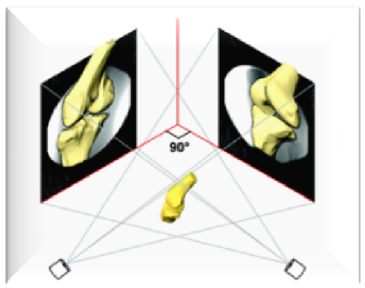
- Frontal and sagittal acquisitions (res 0.18x0.18)
- Low irradiation dose: 7-8 times < classical radiograph: **limitation of the invasivity**
- 3D reconstruction of the lower limb bones in the standing position (NSCP, NSCC algo) : **limitation of the invasivity comparing to CT**
- Acquisition in weight bearing position: **study of physiological position**
- Thin X-ray beam : **No dynamic acquisition**



2D/3D registration of EOS images

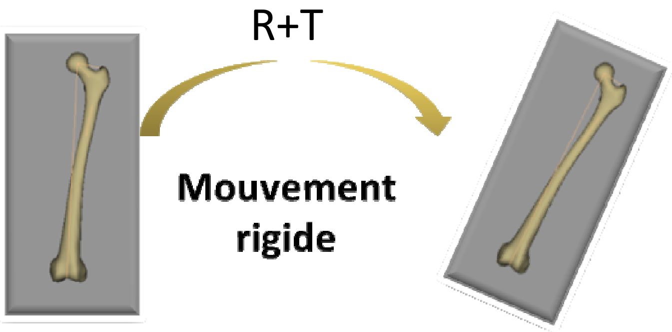
- Classical algorithm





2D/3D registration of EOS images

- Mathematical formulation



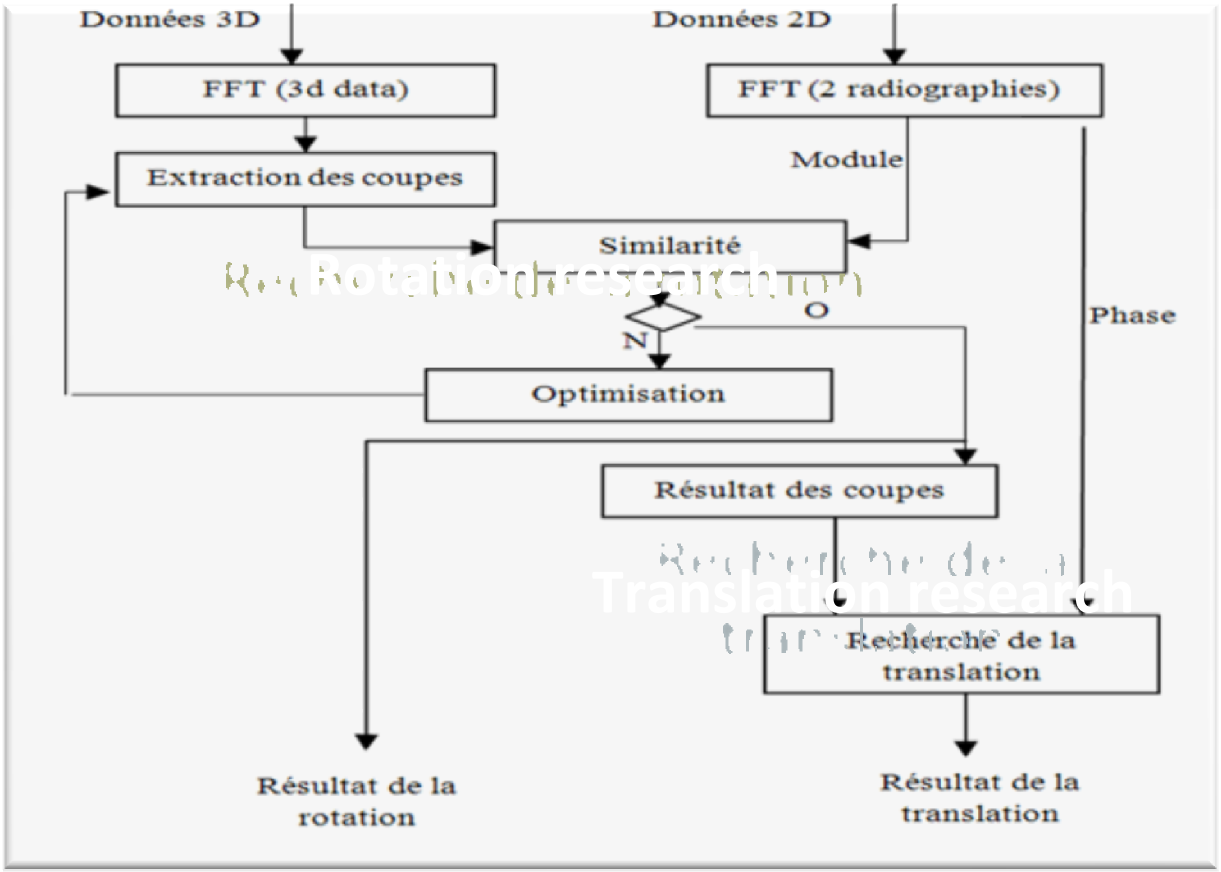
$f_1(x, y, z)$ $f_2(x, y, z)$

Spatial :

Frequencies

- Translations: estimated using phase
- Rotations: estimated using the modulus

Our algorithm



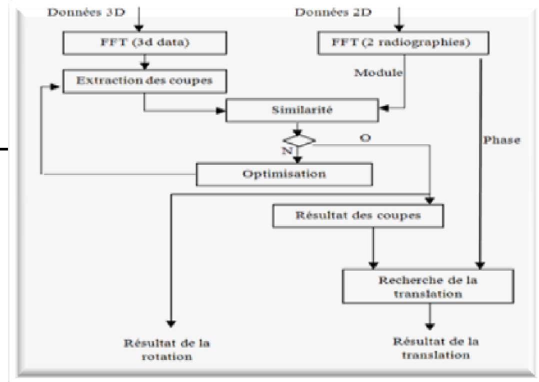
Rotation research

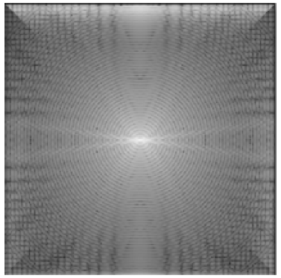
- **Iterative** search of the rotation
  - Modeling : unit quaternion
  - Similarity : L2 metric

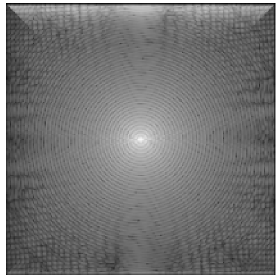
$$d^2((F(I_1), F(I_2)), (F(I'_1), F(I'_2))) = \sum_u \sum_v \left(\|F(I_1)(u,v)\| - \|F(I'_1)(u,v)\|\right)^2 + \sum_u \sum_v \left(\|F(I_2)(u,v)\| - \|F(I'_2)(u,v)\|\right)^2$$

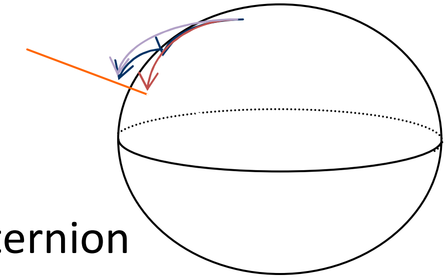
  - Optimization : gradient descent + constraint

$$\begin{cases} q_{t'} = q_{t-1} - \lambda \nabla d(q_{t-1}) \\ q_t = q_{t'} / \|q_{t'}\| \end{cases}$$



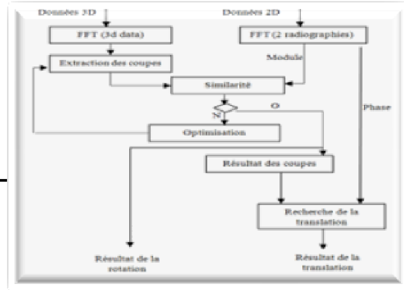






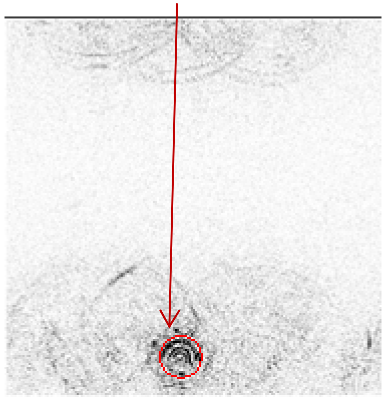
Unit quaternion composition

Translation search

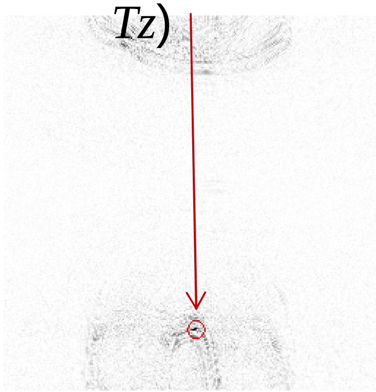


- Decomposition between 2 images

I1 (*Tx Tz*)



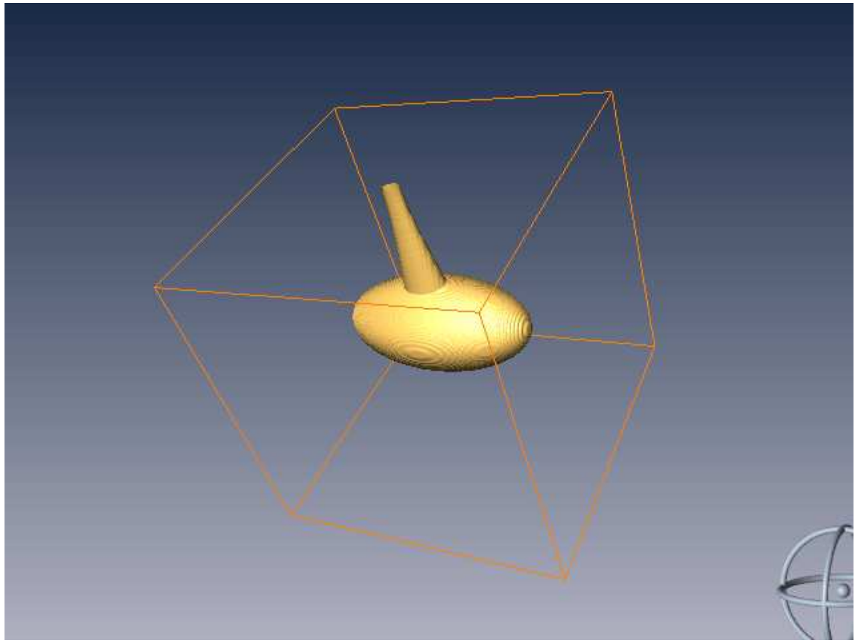
I2 (*Ty Tz*)



•Translations obtained with good precision IF are the rotations .
•Non iterative research

2D/3D registration of EOS images

- Video



2D/3D registration of EOS images

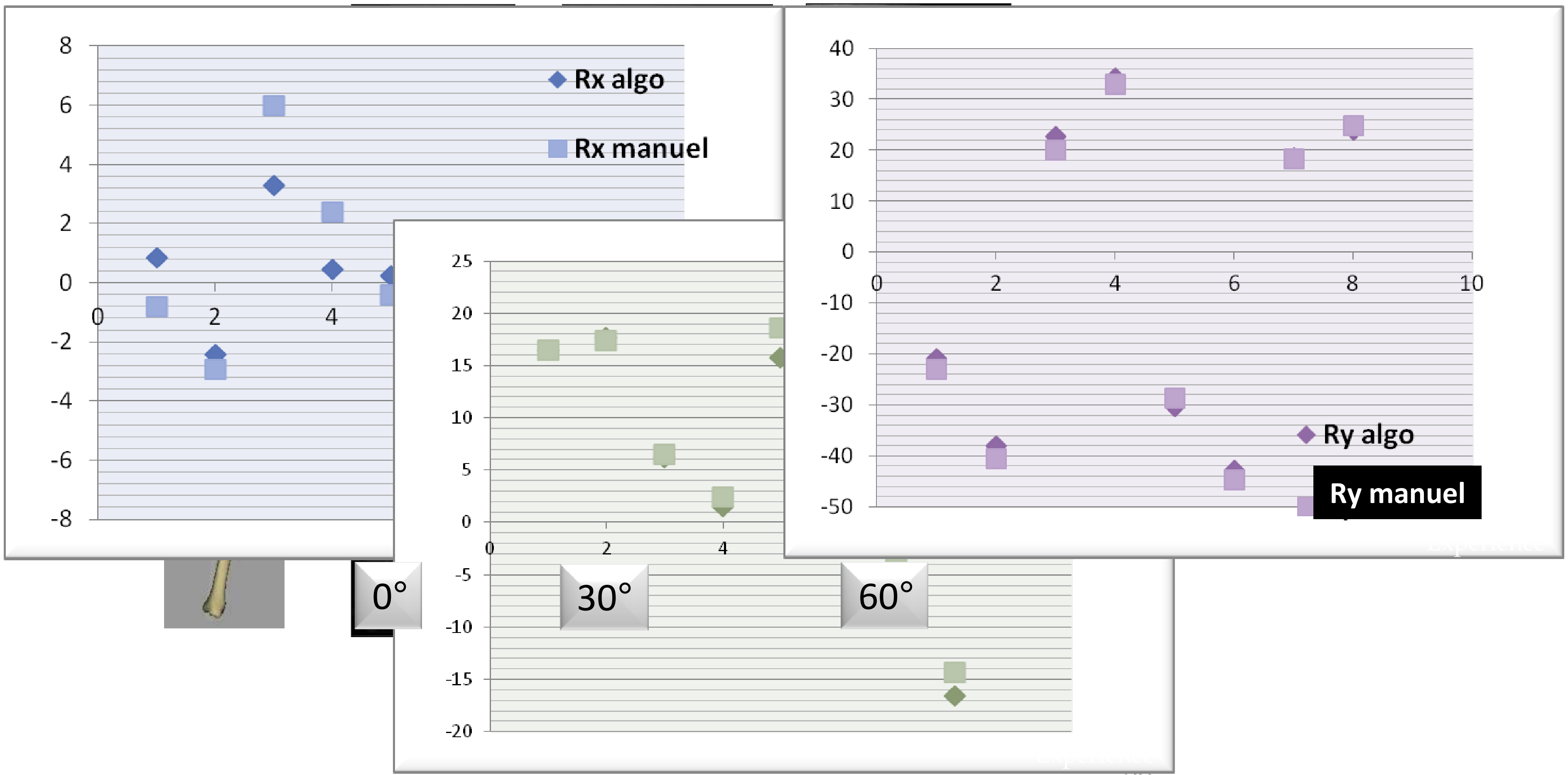
- Link between data in the frequency domain
  - Large range of motion research
- Movement research
  - Iterative search of rotations of the rigid motion
  - Sequential search (rotation and translation) in two homogeneous spaces of 3 dimensions

2D/3D registration of EOS images

- Advantages
  - Without motion constraint (6 DoF).
  - Few user intervention.
  - Generic to articulations: tests on the hip joint and prosthetic bones.

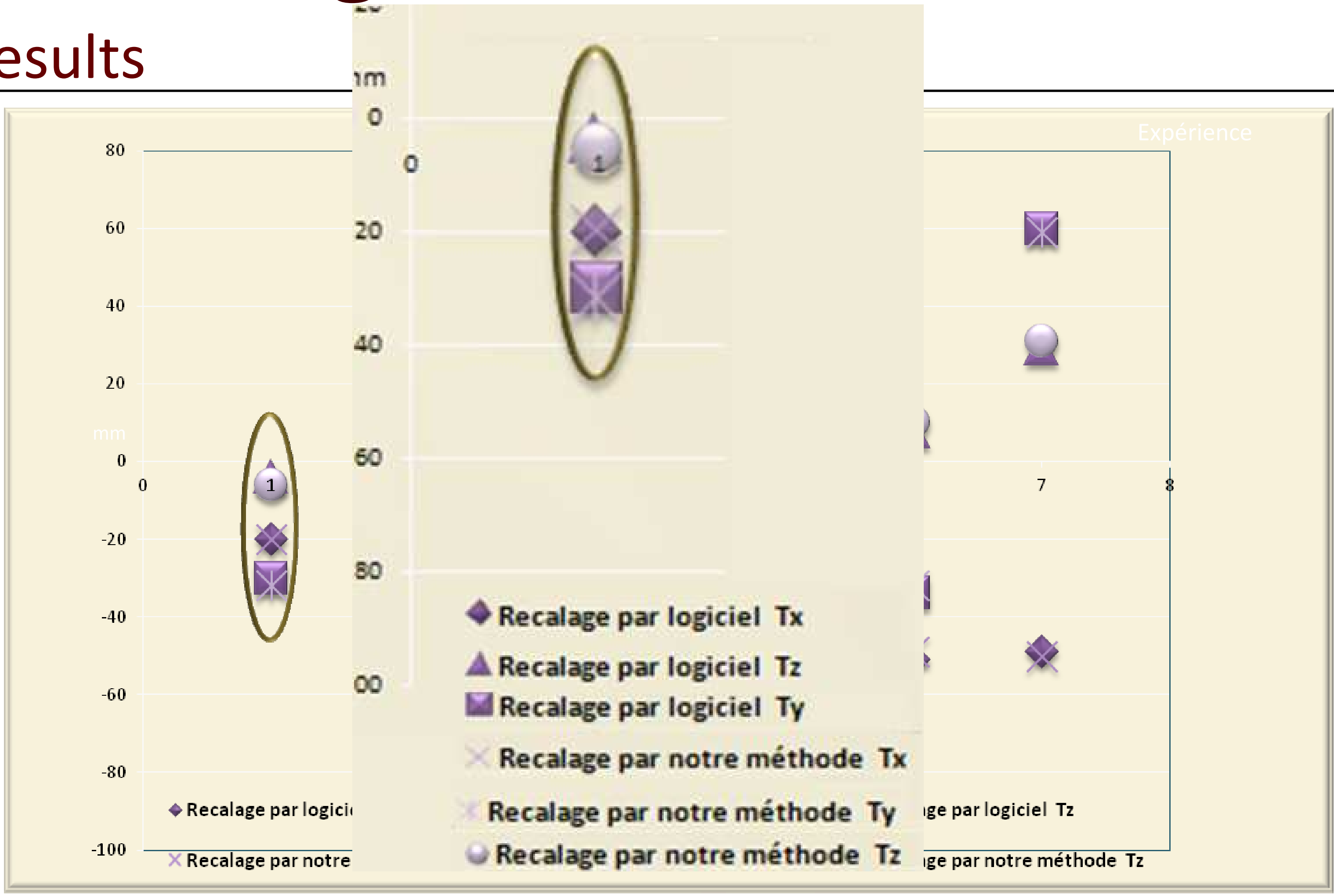
2D/3D registration: results 1

Results Protocol

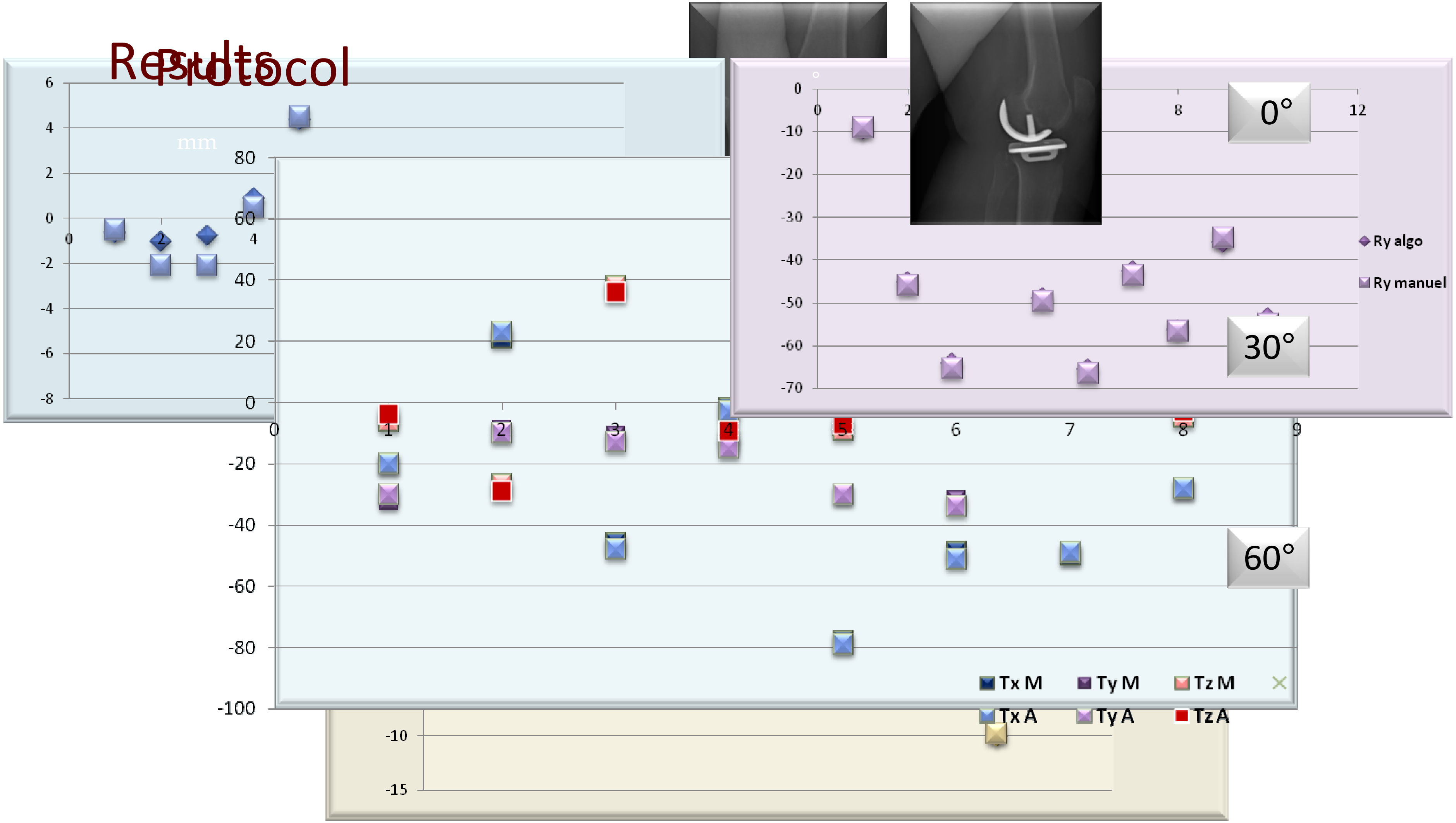


2D/3D registration: results 1

Results



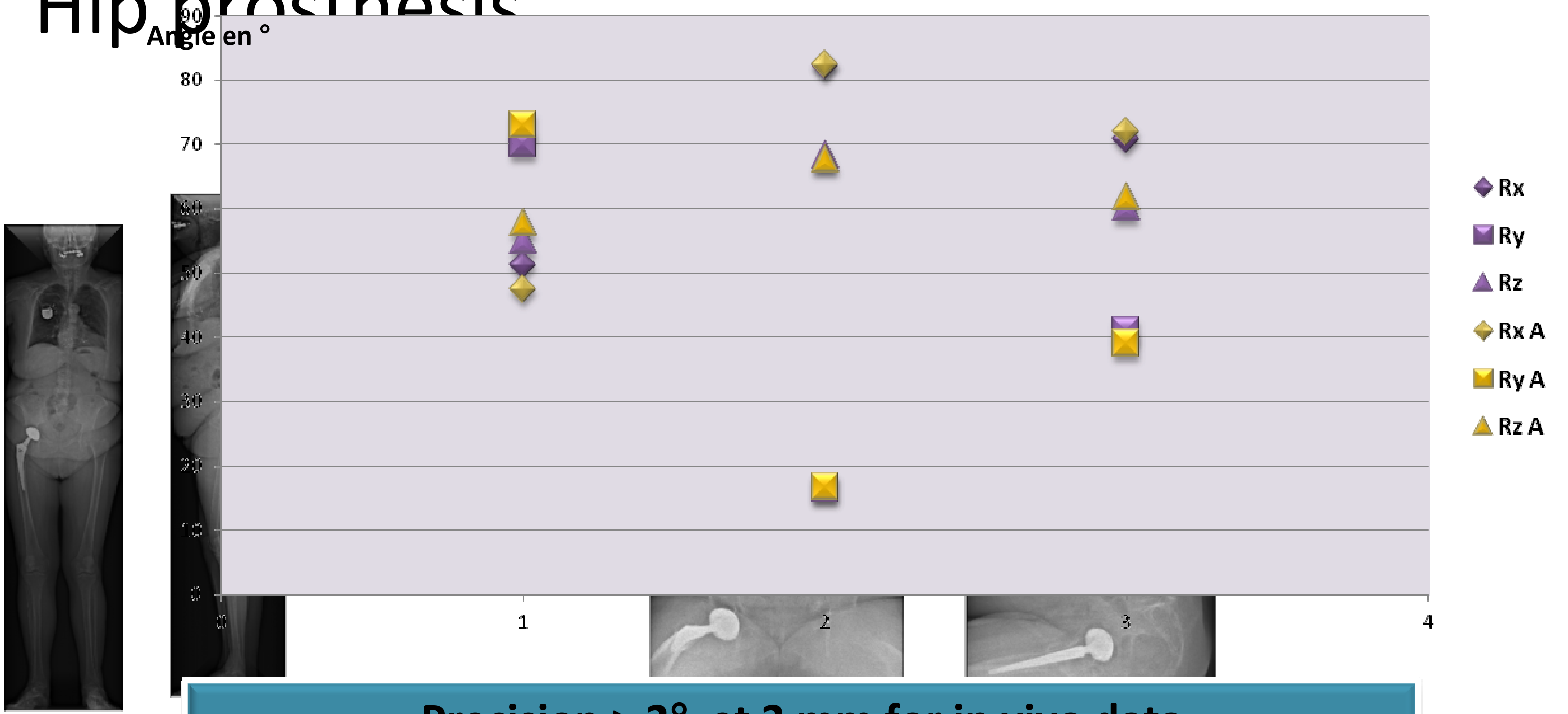
2D/3D registration: results 2



2D/3D registration: results 3

- Results

- Hip prosthesis

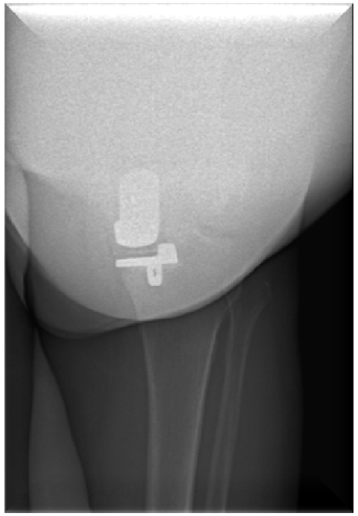


Precision > 2° et 2 mm for in vivo data

2D/3D registration: limitations

- Difficulty in the identification of some structures in some positions
- Use only one radiograph?

Frontal radiography



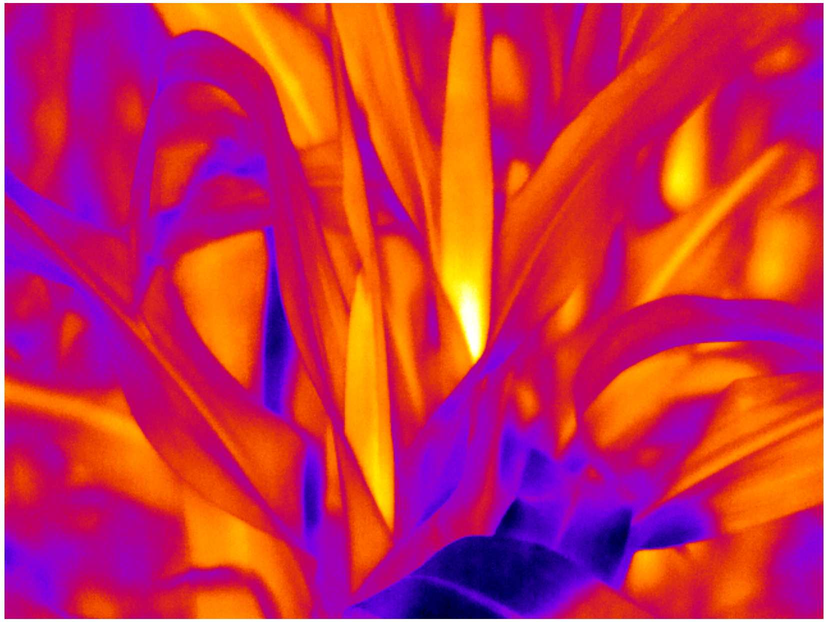
Outline

- Anisotropic diffusion for the MRI segmentation
- 2D/3D registration of EOS images
- **Optic, infra-red and 3D ToF images for the study of the maize plant.**

Optic, infra-red and 3D ToF images for the study of the maize plant.

Aim: Use images to measure the plant transpiration

Period: 1 year

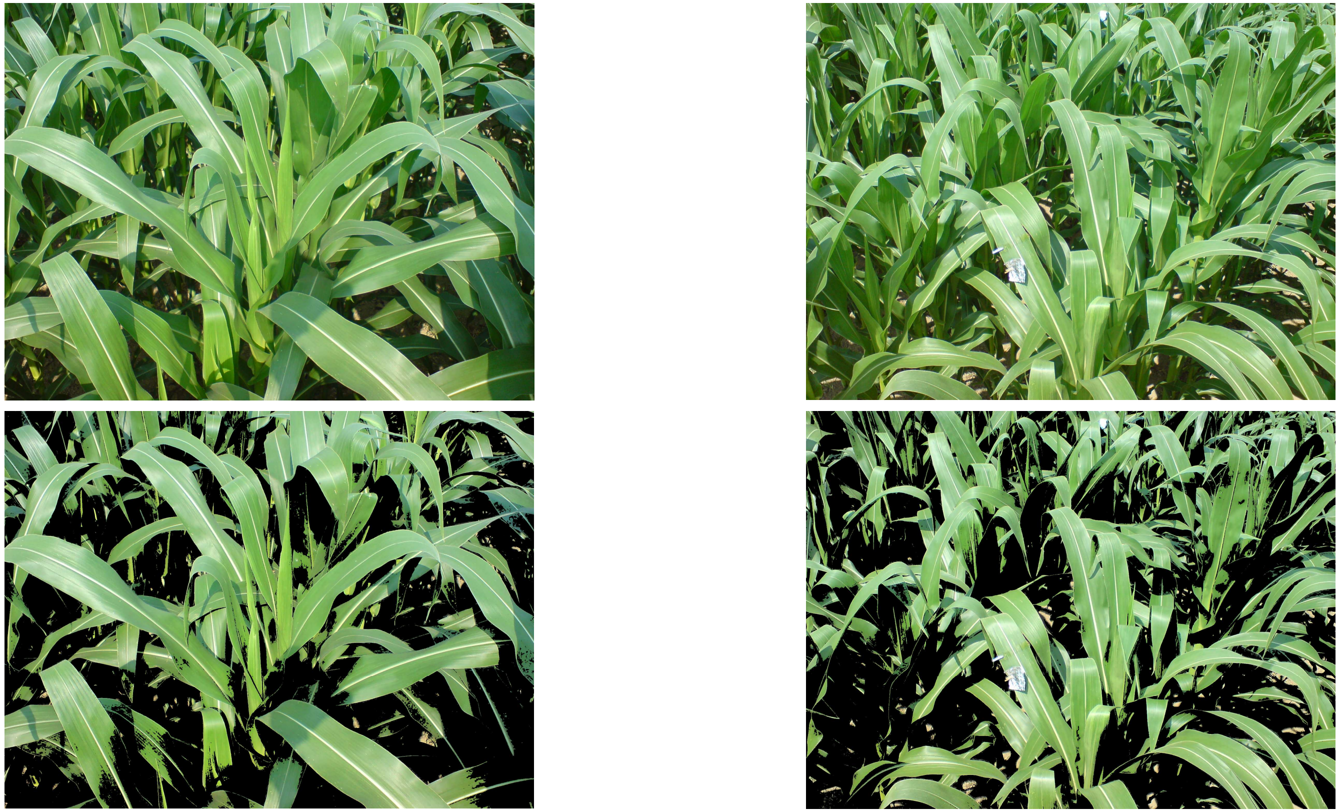


Optic, infra-red and 3D ToF images for the study of the maize plant.

- Problems:
  - Segmentation
  - Shadow detection
  - Registration
  - Data fusion

Optic, infra-red and 3D ToF images for the study of the maize plant

- Primary results



References

- T. Preuβer and M. Rumpf. A Level Set Method for Anisotropic Geometric Diffusion in 3D Image Processing*, SIAM J. Appl. Math., to appear, 2002*
- Taha Jerbi, Valérie Burdin, Julien Leboucher, Eric Stindel, Christian Roux, “2D-3D frequency registration using a low-dose radiographic system for knee motion estimation”, IEEE TBME, 2012 Feb 22.
- R. Ragoubi Hor, V. Burdin, T. Jerbi, O. Rémy-Néris, Pre-Processing of MRI volume using robust anisotropic filtering for shoulder segmentation » IRBM Vol 33, Issue 1, February 2012, pp 11–17
- Taha Jerbi, Valérie Burdin, Faouzi Ghorbel and Jean José Jacq, « Modified data fidelity speed in anisotropic diffusion », 29th Annual International Conference of IEEE Engineering in Medicine and Biology society (EMBC07), Lyon France, August 2007.

Thank You