Registration Methods In Multi-modality Imaging

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Objectives

• Define the terms registration and image fusion

• Present different registration algorithms

• Discuss features and limitations of these

• Match potential algorithms with applicable clinical applications
What is Registration?

• Finding the spatial transform that maps points from one data set to corresponding points in another data set.

• Data sets
  – 2D or 3D Image
  – Intra-operative tool positions
  – Robot coordinates
  – Patient position
A typical registration problem

Coordinates A

Coordinates B
A typical registration problem

What is transformation, $T$?
Why Registration?

Navigation for RFA planning & treatment

Image Guided Robotics for Valve Repair
Why Registration?
Multi modality image fusion

Use of PET & Real-time US
Use of MRI & TRUS
Basic Flowchart

Images A

Similarity Criteria

Optimizer

Images B

Interpolator

Transform

Loop till images match

Registration

similarity value
Basic Flowchart

- A simple 2D rigid rotation transform

The mapping between the coordinate systems of the two images
Basic Flowchart

Images A → Interpolatorator

Transformed Image B

Transform

Registration

Obtain image values of transformed image at required grid points

What is image pixel value at red dots?

loop till images match
Quantitatively measures how well the transformed “matches”

- Are these two images similar? alike? homologous?
- Defining the metric is critical
- No one solution fits all
- Unfortunately, few clear-cut rules
• Based on the metric, modify the transform parameters
• Most registration algorithms require iterative and non-linear optimizers

Basic Flowchart

Update the transform such that the images are as “alike” as possible

Loop till images match

• Based on the metric, modify the transform parameters
• Most registration algorithms require iterative and non-linear optimizers
Basic Flowchart

Images A

Images B

Similarity Criteria

Optimizer

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Loop till images match

Registration

similarity value
Rigid Transform

- Rigid rotation & translation transform
- 2D or 3D
- Max 6 independent parameters
  - three translations in X, Y, Z directions
  - three rotations about X, Y, Z axis

\[ T(x) = R \cdot x + p \]
Affine Transform

- Deceptively simple & Tricky
- Scaling has non-linear effects
- Max 12 parameters

\[ T(x) = A \cdot x + p \]
• A special case of non-rigid transform
Non-rigid Transform

• Type of transform largely application driven

• Example
  • Modeling image as a continuum - plastic, elastic
  • Volumetric deformation fields

• Under-constrained, almost infinite dimensional
<table>
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<tr>
<th>Typical Usage</th>
<th>Rigid</th>
<th>Non-Rigid</th>
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<tr>
<td>• Approximately “fuse” multiple images</td>
<td>• Register different patients</td>
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<tr>
<td>• Transfer coordinates between tracker and images</td>
<td>• Study over a large time period</td>
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<td>• Image guided robot assistance</td>
<td>• Compensate for deformation during US image acquisition</td>
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<td>• Initialize non-rigid transformations</td>
<td>• Atlas-based Segmentation</td>
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</table>
Basic Flowchart

Images A

Images B

Similiarity Criteria

Optimizer

Loop till images match

Interpolator

Transform

Registration

similarity value

Loop till images match
Similarity Criteria

- Internal Fiducial
- External Fiducial
- Surfaces
- Vessels, etc
- Mutual Information
- Voxel property

Landmark

Low Complexity

Segmentation

Intensity

Complexity
Point to Point Landmark

Extrinsic
• Stereotactic frame
• Screw markers
• Skin markers

Intrinsic
• Anatomical point landmarks identified by user

Criteria:
Sum of square distances between landmarks
Point to Point Landmark Registration

• Requires two sets of N points, N > 3

• Robust, versatile, very fast

• Finding correspondence

• Transfer coordinates between tracker & images

• In practice, limited to rigid/affine transformations
Point to Point Landmark Registration

Example

**Step 1**
Identify points in first image set

**Step 2**
Match corresponding points using tracker

Traxtal, Inc
Segmentation based

• Extract structure (surface, and curve)
• Criteria:
  – Depends on structure
• Segmentation can be range from automatic-manual
  – Largely defined by application
  – Segmentation effects accuracy
• Applicable to non-rigid, lower computational complexity
Surface to Surface Registration Example

Step 1
Identify surface in MRI

Step 2
Automatic segmentation in axial TRUS

Step 3
Semi-Automatic 3DUS/MRI

Xu S, Philips Research
Surface to Surface Registration Example

- 2D US/3D MRI registration is sensitive
- Multiple images increase robustness
- Accuracy up to 3mm
- Motion compensation
  - Using 3D US / TRUS registration
  - Improved MRI / US overlap
Voxel property

• Derived full image content
• Most flexible
• Considerable computation costs
• Common Criteria:
  – Absolute difference of intensities
  – Mean squares difference of intensities
  – Cross-correlation
  – Mutual information
Elasticity based registration
Elasticity based registration
3D-3D Rigid Registration
Mean Squares Example

• Series of images at different interval
• Same Imaging modality
• Simple, less computationally expensive
3D-3D Deformable Example

Initial Atlas
(mean shape and shape modes)

Subject CT scans

Deformable 3D/3D registration

Updated Atlas

Update Atlas / statistics

Deformed Mesh Instances

Warped CT scans (to meanshape)

Statistical Atlas

Boot-strapping Loop

Chintalapani G, MICCAI, 2007
3D-3D Deformable Example

Step 1

• Start with a initial approximate atlas, subject CT scans, subject mesh
• Do a Rigid registration
• Obtain a mean CT-like volume, mean shape and modes

Chintalapani G, MICCAI, 2007
3D-3D Deformable Example

Step 2
• Do a deformable registration of the CT scans to mean CT-like volume
  – Uses prior knowledge
  – Increases registration accuracy

Chintalapani G, MICCAI, 2007
3D-3D Deformable Example

Step 3

• Generate mesh from deformably registered CTs
• Create a new atlas from the deformed mesh
3D-3D Deformable Example

Step 4

• Repeat steps 2 & 3 until satisfied
Summary

- Define the terms registration and image fusion
- Different methods based on need
- Scope and limitations
- Clinical applications
References

• Toolkits
  – ITK ( itk.org )
  – MITK ( mitk.org )
  – MeVisLab ( mevislab.de )
  – Slicer ( slicer.org )

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