Image fusion for target delineation

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Road map

- Why do we need one or more imaging modalities?
- Why do we currently plan only on an axial CT scans?
- The need to co-register other imaging modalities with CT images
- Concept of image registration and fusion
- Uncertainties and limitation in this process
Why do we need one or more imaging modalities?

CT  Post-Gd T1w  FLAIR
Multimodality for target delineation

CT
e- density
bone/ air
geometric

MR
soft tissue
orientation
spectra!

NM
physiology
perfusion

Each modality provides some complimentary information over both space and time!
Why do we currently plan only on an axial CT scan?

- High spatial integrity
- High spatial resolution
- Excellent bone structure depiction
- Ability to provide relative electron density map for radiation dose calculation
- CT is performed only on Axial projection
- Axial 3D data set is used to define reference origin enabling virtual simulation
MRI imaging

Advantages of MRI
• Superior soft tissue
• Richness in various contrasts
• Anatomic, metabolic and functional

Limitation of MRI (geometric distortion):
• Magnetic field strength
• Magnetic gradient field non linearity
• Magnetic susceptibility
• Lack of relative electron density values for dose calculation

Distortion range from 0.2 to 5 mm as the distance from the centre of the magnetic field increases from 5 to 10 cm.

Apparent curvature of the tubes at ‘A’ & Their disappearance at ‘B’ due to warping distortion of the imaging plane

Object-induced distortion in the form of discontinuities at ‘C’

# Imaging modality resolution

<table>
<thead>
<tr>
<th>Modality</th>
<th>Resolution</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Spatial</td>
</tr>
<tr>
<td>CT</td>
<td>0.5 - 1mm</td>
</tr>
<tr>
<td>MRI</td>
<td>1 - 2 mm</td>
</tr>
<tr>
<td>PET</td>
<td>3 - 4 mm</td>
</tr>
<tr>
<td>SPECT</td>
<td>8 - 12 mm</td>
</tr>
</tbody>
</table>

+++ : High, ++ : medium, + : low
Co-register other imaging modalities with CT images (and also with one another)

Radiotherapy CT performed in treatment position

MR, SPECT, PET

Diagnostic pre-operative CT

MR (B0) reference image for DTI maps
Image registration & fusion

- Initial diagnosis and staging
- Treatment planning and delivery
- To monitor during / after therapy
- 2D and 3D image fusion at the treatment unit to aid patient setup
- For adapting and customizing treatment during the course of therapy using 3D and 4D anatomic and functional imaging
The process to image registration involves searching for the best spatial transformation between two images.

**Geometrical features**: point like anatomic or surfaces

**Intensity similarity measures**: cross correlation, squared intensity differences or mutual information
Image registration & fusion

Rotation
Translation
Rigid body transformation

Rotation
Translation
FOV (Field of View) - No Scaling
The object do not change in shape

200 mm

200 mm

200 mm

200 mm
Rigid body transformation

• Identical patient orientation during different imaging studies
• Single global transformation for all points in the two imaging studies
• Dual imaging modality devices such as PET-CT or SPECT-CT
• Assumption physiological motion is controlled or absent
Affine transformation

Different FOV (Field of View)
Scaling Required
Involves translations, rotations and scaling
The parallelism of the straight line is preserved
Image registration & data fusion

- **Transformation model:**
  Single global transformation
  6 DOF
  (Three rotation and three translation)
  To a completely free deformable model
- **Metric used to measure how well the images are (or not) registered**
- **Optimizer used to align both the data sets**
## Rigid transformation: algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks [26, 27]</td>
<td>Simple and robust. Unbiased in absence of distortion</td>
<td>Accuracy depends on the number of landmarks. Good internal landmarks difficult to find. External landmarks are sensitive to MRI distortion</td>
<td>General purpose. Gold standard for evaluation of other algorithms</td>
</tr>
<tr>
<td>Interactive [28, 29]</td>
<td>Easy to use</td>
<td>Slow and not very accurate</td>
<td>General purpose</td>
</tr>
<tr>
<td>Frame-based [30]</td>
<td>Highly accurate with CT</td>
<td>Invasive procedure. Frame is very sensitive to MRI distortion</td>
<td>Stereotactic RT</td>
</tr>
<tr>
<td>Contours [31–33]</td>
<td>Fast and accurate</td>
<td>Contouring required</td>
<td>Soft tissues</td>
</tr>
<tr>
<td>Chamfer matching (based on automatic segmentation) [34–37]</td>
<td>Fast and accurate</td>
<td>Automatic segmentation requires careful tuning</td>
<td>Bone (i.e., skull, pelvis, lung)</td>
</tr>
<tr>
<td>Volume matching [38–40]</td>
<td>Little preprocessing required. Works extremely well for same modality registration</td>
<td>Slow. Highly sensitive to organ motion</td>
<td>Brain</td>
</tr>
</tbody>
</table>
Limitation : Global Rigid transformation

- The assumption of global rigid movement of anatomy is often violated, especially for sites other than the head.

- Large image volumes that extend to the body surface:
  - Differences in patient setup (arms up versus arms down).
  - Organ filling and uncontrolled physiological motion confound the use of a single affine transform to register two imaging studies.
Limitation : Global Rigid transformation
Local rigid transformation

- Possible to use a rigid or affine transformation to register sub-volumes of two imaging studies

Simple geometric cropping

Piecewise cropping

Anatomy based cropping
Influence of slice thickness
Image fusion validation tools

- Display with linked cursor
- Split screen display
- Chess
- Colorwash overlay

- Spy glass
- Overlay CT / MR
- Overlay of image with Edge detection
Where do we require deformable registration?

The bladder and rectum contours transferred to MR shows these organs shape is changed.
Deformable model

- The deformation due to change in shape, motion
- The parallelism of the straight line is not preserved
Conclusion

• The need for fusion is obvious as the target is delineated with different degrees of anatomic details in various imaging modalities with the ultimate aim to refine human perception.

• The process has different grades of complexity:
  - Simple global translation (Rigid model)
  - Global translation and scaling (Affine model)
  - Local solution (when dealing with non-rigid structures)
  - Complex transformation involving rescaling at the voxel level (Deformable registration)

• Challenges:
  - Validation methodologies for non-rigid registration algorithms
  - More robust similarity measures
  - Distinguish between rigid and deformable structures
  - Novel display techniques