Medical Image Analysis

CS 778 / 578

Computer Science and Electrical Engineering Dept.
West Virginia University

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Outline

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Problem Definition

Image registration is the process of determining a coordinate transformation between two images that are misaligned.

$$\min_T dist(I_1(\mathbf{x}), I_2(T(\mathbf{x})))$$

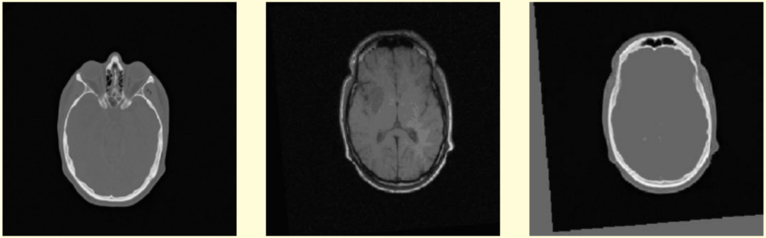
- T is a coordinate transformation
- $I_1(\mathbf{x})$ and $I_2(\mathbf{x})$ are 2 images to be aligned
- $dist(I_1, I_2)$ is a metric which determines how well the images match.
- $dist(I_1, I_2)$ can be based on image intensities or extracted features.

Examples

Panorama Stitching

Examples

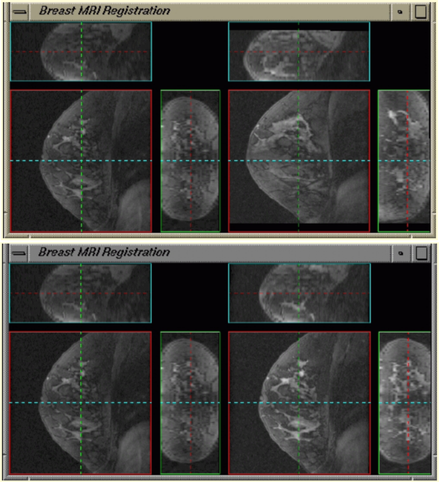
Multimodal rigid registration



(CT - MR registration)

Examples

Unimodal nonrigid registration



Some Applications

- Determine a correspondence between function (PET, fMRI) and anatomy (MRI, CT).
- Longitudinal studies of individuals over time.
- Comparison of different subjects.

Outline

1. Image Registration
2. Classification of Registration Methods
3. Overview of imaging modalities

Criteria

From ”A Survey of Medical Image Registration” by J. Maintz and M. Viergever.

1. Dimensionality of images.
2. Nature of registration basis (markers, landmarks, intensity)
3. Nature of transformation (translation, rotation, elastic)
4. Domain of transformation (global, local)
5. Interaction (interactive, automatic)
6. Optimization procedure (computation, search).
7. Modalities involved (CT, MRI,...)
8. Subject (Same patient?).
9. Object (anatomical region).

1. Dimensionality

Medical images may be 2D, 3D, or even “4D”.

- 2D: projections (x-ray) or slices of volumes.
- 3D volumes (CT, MR).
- “4D” : time series volume images (cardiac motion).

We may wish to register:

- a) Spatial Dimensions
  1. 2D / 2D
  2. 2D / 3D
  3. 3D / 3D
- b) Time Series
  1. 2D / 2D
  2. 2D / 3D
  3. 3D / 3D

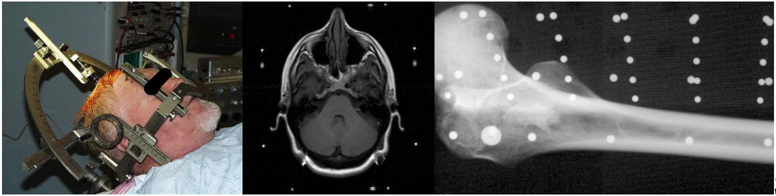
- 3D / 3D is most common.
- Increasing dimension leads to more complex transformations and metrics.

2. Nature of registration basis

- a) Extrinsic : foreign objects in the image volume.
- b) Intrinsic : based on the subject being imaged.
- c) Non-image based : calibrated coordinate systems, multimodal scanners (PET-CT hybrid).

2. Nature of registration basis

- a) Extrinsic
  1. Invasive
     - ★ A. Stereotactic frame
     - ★ B. Fiducials (screw markers)
  2. Non-invasive
     - ★ A. Foam mold, frame, dental adapter
     - ★ B. Fiducials (skin markers)



Stereotactic frame (left) and resulting image (center). Noninvasive skin markers (right).

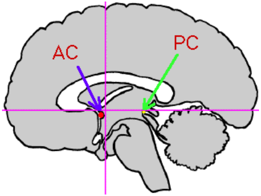
2. Nature of registration basis

- b) Intrinsic
  1. Landmark based
     - A. Anatomical
     - B. Geometrical
  2. Segmentation based
     - A. Rigid models (points, curves, surfaces)
     - B. Deformable models
  3. Voxel property based
     - A. Reduction to features (centroid, principal axes)
     - B. Using full image content

1. Landmark based

Anatomical Landmarks:

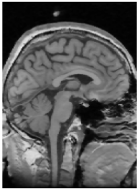
Sparse set of points based on known anatomy.

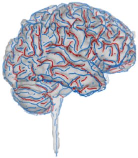


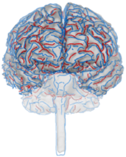
(Anterior commissure - Posterior commissure)

Geometrical Landmarks:

Corners, curvature maxima.







2. Segmentation based

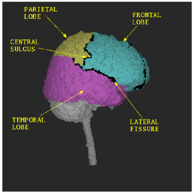
Segment the same structure from both images, then align these structures.

Rigid Models:

Matching edges and surfaces.

Deformable Models:

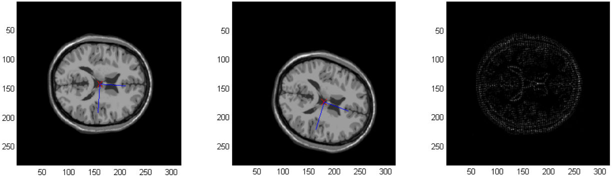
Snakes, Deformable atlases.



Accuracy of the registration is limited by the accuracy of the segmentation.

3. Voxel property based

Reduction to features:

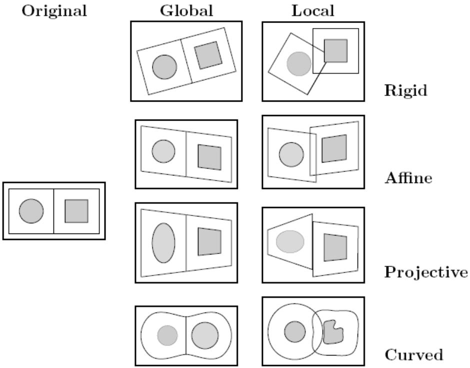


Centroid, principal axes of the images.

Using full image content:
Image intensity.

Nature and domain of transformation

- 3) Nature of transformation
  - a) Rigid
  - b) Affine
  - c) Projective
  - d) Curved
- 4) Domain of transformation
  - a) Local (rarely used)
  - b) Global



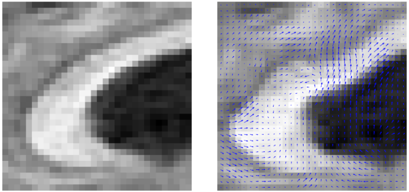
Nature and domain of transformation

Represented by matrices

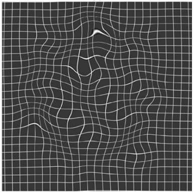
- a) Rigid : Rotation, translation, reflection (preserves perpendicularity)
- b) Affine : shear (preserves parallelism)
- c) Projection : 2D-3D registration

Nature and domain of transformation

- d) Curved, Elastic



Smooth vector displacement field



Polynomial transformation (b-splines)

5. Interaction

- a) Interactive
  1. Initialization supplied
  2. No initialization supplied
- b) Semi-automatic
  1. User initializing
  2. User steering / correcting
  3. Both
- c) Automatic

6. Optimization procedure

- a. Parameters computed (explicitly)
- b. Parameters searched for (iterative techniques)

Explicit computation is generally possible only when the number of parameters is small, as when registering small point sets.

Search: Iterative techniques, like gradient descent may be used to optimize the energy function.

7. Modalities involved

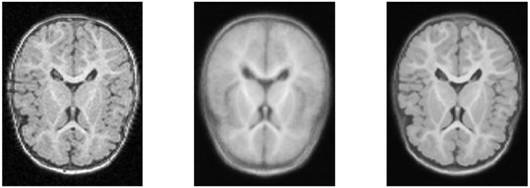
- a. Monomodal
  - Time series
  - Pre and post contrast enhancement
- b. Multimodal
  - Structural - Structural
  - Structural - Functional
- c. Modality to model
  Mathematical models of anatomy or pathology.
- d. Patient to modality
  (interoperative or radiotherapy applications)

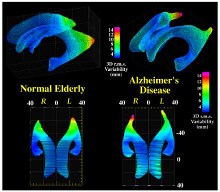
8. Subject

- a. Intrasubject (same patient)
- b. Intersubject (different patients)
- c. Atlas (statistical database)

Atlas

- Statistical atlases are models of expected or 'normal' anatomy.
- May be constructed by sampling from large population of images.
- These samples are registered to a common coordinate system and 'averaged'.





9. Object

Most frequently:

- a. Head
- b. Thorax
- c. Abdomen
- d. Pelvis
- e. Limbs
- f. Spine and vertebrae

Outline

1. Image Registration

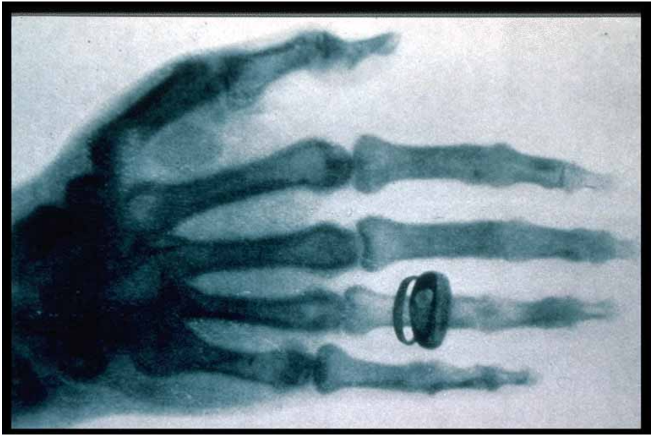
2. Classification of Registration Methods

3. Overview of imaging modalities

X-ray

- Physical basis: X-rays are attenuated (absorbed or scattered) by hard tissue and may pass through soft tissue.
- Hardware: X-ray tube and detector.
- Image formation: Photographic plate, or electronic detector (scintillator)
- Applications: Skeletal structure, mammography, angiography (with contrast agent)

X-ray



Poor soft tissue contrast in X-ray.

CT

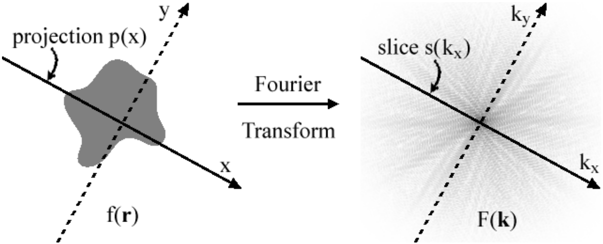
Computed tomography

- Physical basis: Same as x-ray. Injected or swallowed contrast agents can change attenuation in soft tissue.
- Hardware: Rotating ring of x-ray tubes and detectors.
- Image formation: Multiple projections are used to reconstruct a 3D volume.
- Applications: Skeletal and organ structure.
- Problem: Risk associated with radiation exposure.

Tomographic reconstruction

Projection slice theorem :

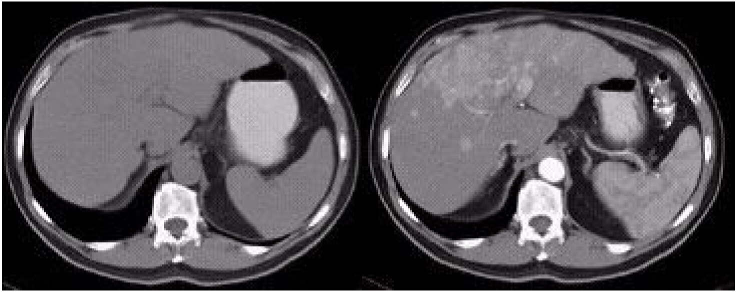
If $f(r) \leftrightarrow F(k)$, FT of a projection of $f(r)$ = slice of $F(k)$.



- More projections give a more complete $F(k)$
- Resample $F(k)$ onto a rectangular grid
- Apply inverse FT to obtain $f(r)$

CT

Contrast enhancement in CT.



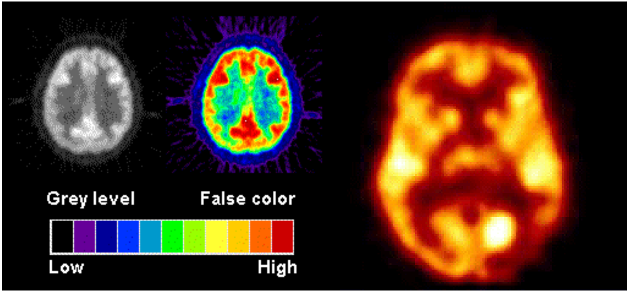
Abdominal CT without contrast (left), with contrast (right).

PET

Positron emission tomography.

- Physical basis: Injected radio nuclide decays, emitting a positron. Positron-electron collision results in a pair of photons. Rate of absorption of the tracer indicates metabolic function.
- Hardware: Array of photomultiplier tubes and radiation detectors.
- Image formation: Tomographic reconstruction as in CT
- Applications: Oncology, functional brain imaging
- Problem: Low spatial resolution

PET



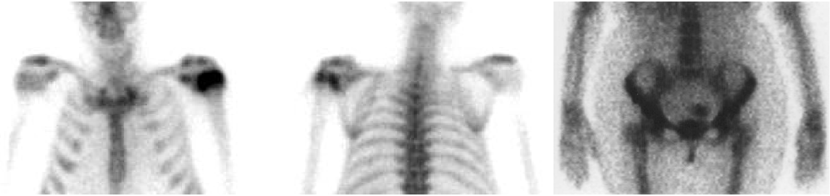
False color PET visualization (left), Tumor (right).

SPECT

Single Photon Emission Computed Tomography.

- Physical basis: Injected radio nuclide decays, emitting a gamma ray (photon).
- Hardware: Similar to PET
- Image formation: Tomographic reconstruction as in CT
- Applications: Cardiac perfusion imaging, brain function, tumor imaging.
- Problem: Low spatial resolution, markers have a longer half-life than those used for PET.

SPECT



SPECT image of arthritic shoulder (left), broken pelvis (right).

Ultrasound

- Physical basis: 2-10 MHz acoustic (pressure) waves are partially reflected by tissue boundaries. Time delay and intensity of the reflected signal depend on tissue properties and depth.
- Hardware: Array of piezoelectric transducers.
- Applications: Soft tissue - Abdominal organs, obstetrics
- Problem: Low resolution, noisy images.

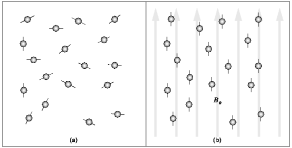
Ultrasound

Ultrasound (left), 3D ultrasound (right).

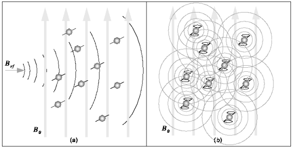
MRI

Nuclear magnetic resonance:

Hydrogen nuclei are magnetic dipoles, and tend to align in a magnetic field.



During an applied RF pulse the nuclei tip away from the direction of the magnetic field and precess in phase with each other. After the RF pulse, these nuclei emit RF energy as they return to equilibrium.



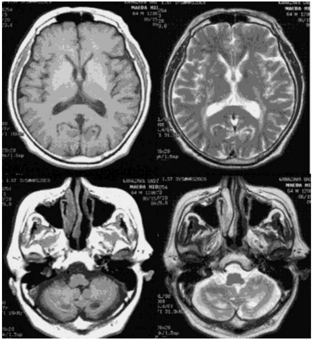
Images from "Intracranial Boundary Detection and Radio Frequency Correction in Magnetic Resonance Images"

(http://www.cs.sfu.ca/ stella/papers/blairthesis/main/main.html)

MRI

- Physical basis: Nuclear magnetic resonance.
- Hardware: Electromagnet and RF coils.
- Image formation: Reconstructed by FT
- Applications: Soft and hard tissue structure. Dependent on pulse sequence and contrast agent.
- Problem: Long scan time, acoustic noise, artifacts.

MRI

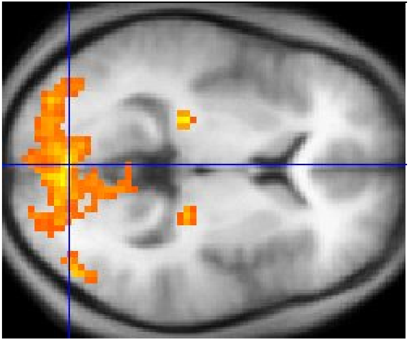


RF pulse sequence and time of acquisition determine contrast of the image.

fMRI

- Physical basis: Neural activity changes blood flow and oxygenation. Blood oxygenation level changes MRI signal contrast.
- Hardware: Same as MRI
- Image formation: Similar to MRI
- Applications: Brain function

fMRI



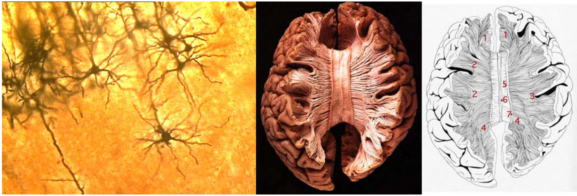
Functional MRI with activation shown in false color, overlaid on structural MRI.

Other MRI modalities

- MRE (Magnetic resonance elastography) can compute mechanical properties of imaged tissue. This is useful in muscle studies, such as the heart, and tumor detection.
- Perfusion MRI can detect large scale blood flow. Hemodynamic studies are useful for diagnosing certain brain, heart and vascular diseases.
- DT-MRI (Diffusion tensor MRI) can detect small scale water diffusion. This is useful in determining the orientation of fiberous tissue, primarily in the brain and spinal cord.

DT-MRI

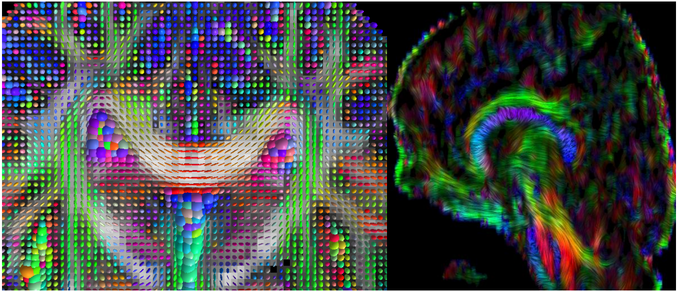
Axonal fiber bundles in neural tissue act as a barrier to the diffusion of water. By observing the directional properties of water diffusion we may indirectly infer the direction of fiberous tissue.



Individual axonal fibers (left)
and fiber bundles in dissected human brain (right).

DT-MRI

A tensor model of diffusion is fit at each voxel. The dominant direction (vector) of diffusion may be computed from the tensor. Fiber pathways may be traced through the vector field.



The diffusion tensor, visualized as an ellipsoid at each voxel (left) synthesize texture representing fiber orientation (right).

Registration

Registering images of different modalities is a difficult challenge. Before we attempt this we will look at an approach to unimodal image registration.