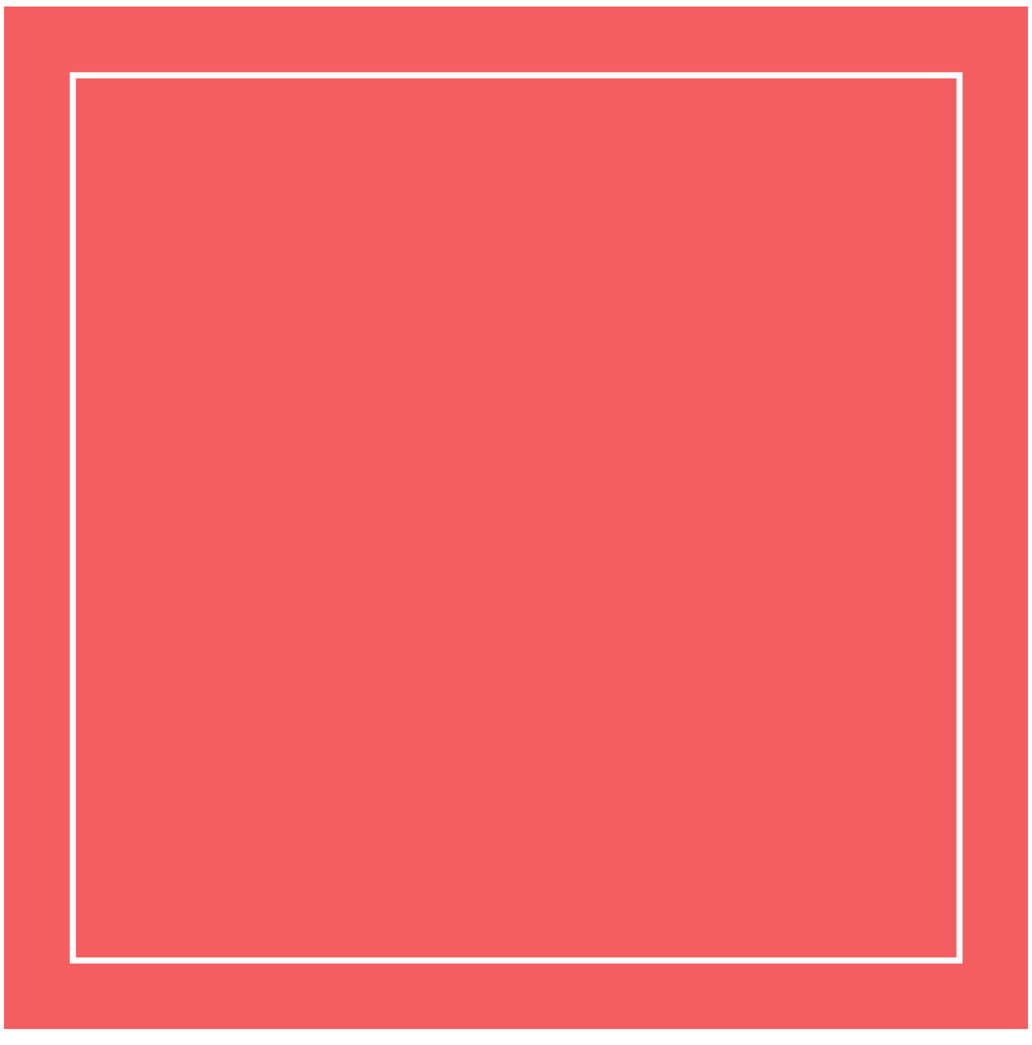


Introduction

<u>Registration</u>

- Registration is the process of aligning two or more images to compare or analyze changes.
- It is widely used in medical imaging to track changes over time or match images from different patients.

<u>Types of Registration</u>

- **Rigid Registration:** Only allows movement (translation & rotation).
- **Affine Registration:** Allows movement, scaling, and skewing.
- **Non-Rigid Registration:** Allows bending and deformation, making it useful for soft tissues.

Non-Rigid Registration

- **Rigid and affine transformations are not enough** for soft tissues that deform, like the brain, heart, or lungs.
- Non-rigid registration helps in **motion tracking and deformation analysis**, useful in surgery, disease monitoring, and biomechanical studies.

Techniques in Non-Rigid Registration

1. Elastic & Fluid Registration
2. Finite Element Models (FEM)
3. Optical Flow
4. Spline-Based Methods
    a. Thin-Plate Splines
    b. B-Splines

Elastic Registration

Elastic registration adjusts **images** by **smoothly stretching** and **bending** them to match a **reference**. It uses **flexible, physics-based models** that **mimic elasticity**, ensuring **natural transformations**. The goal is to create the **best possible alignment** by balancing **smoothness** and **accuracy**.

Techniques Used in Elastic Registration:

1. **Lagrangian Reference Frame** – Describes deformations based on their **initial position**.
2. **Elastic Energy Minimization** – Balances **smoothness** and **accuracy** for natural transformations.
3. **Finite Element Methods (FEM)** – Uses **mathematical models** to simulate **elastic deformations**.

Fluid Registration

Fluid registration warps **images** like a **flowing liquid** for **seamless alignment**. It uses **flexible models** that **adapt naturally**. By balancing **smoothness** and **accuracy**, it ensures **precise matching**. This method is ideal for **detailed** and **dynamic transformations**.

Techniques Used in Fluid Registration:

1. **Navier-Stokes Equation** – Governs fluid-like deformations by solving for velocity fields instead of displacement fields.
2. **Convolution-Based Solution** – Uses eigenfunctions of the elasticity operator to speed up computation, improving efficiency.
3. **Variable Viscosity Models** – Allows different deformation strengths across image regions for more adaptive transformations.

Registration Using FEM

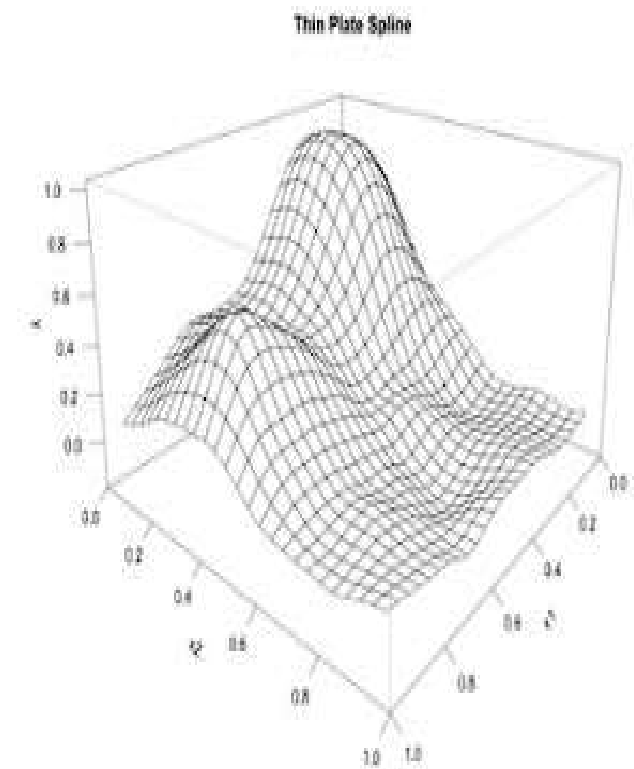
Finite Element Methods (FEM) help model **elastic deformations** in **image registration**. **Edwards et al.** proposed a method for **surgery guidance** by dividing images into a **triangular mesh**. **Nodes** represent different **tissues—bones (rigid), soft tissues (elastic),** and **cerebrospinal fluid (fluid). Rigid nodes** stay **fixed**, while **elastic** and **fluid nodes** deform for **realistic alignment**.

Registration Using Optical Flow

Optical flow tracks **pixel movements** between images to estimate **deformation**. It calculates **motion** by analyzing **brightness changes**, helping **align images** smoothly and accurately. This method is widely used in **medical imaging** and **video processing**.

Thin-Plate Splines (TPS)

Thin-Plate Splines (TPS) is a method for **smooth and flexible transformations** in **image registration** and **shape matching**. It minimizes **bending energy** to ensure **natural deformations** while preserving structure. TPS is widely used in **medical imaging, computer vision,** and **biometric recognition**.



B-Splines

B-Splines (Basis Splines) are used for **smooth and flexible transformations** in **image registration** and **shape modeling.** They provide **local control** over deformations, ensuring **precision and continuity**. B-Splines are widely applied in **medical imaging, computer graphics,** and **geometric design**.

Intersubject Registration (ISR)

- Intersubject registration is a non-rigid image registration technique that aligns anatomical structures across **different individuals**
- **ISR accounts for anatomical variability between subjects**, enabling cross-population comparisons.
- Used in **population studies, medical atlases, and disease analysis**.
- **Key Characteristics:**
    1. **High Degrees of Freedom:**
        - ISR transformations have more flexibility than intrasubject registration to accommodate inter-individual shape variations.
    2. **Less Constraint on Deformation:**
        - Unlike intrasubject registration, where deformations are limited to biological consistency, ISR allows greater anatomical adaptation.

Techniques Used in ISR

1. **Elastic & Fluid Registration**

- **Elastic Registration** – Treats tissue like **rubber**, allowing smooth stretching.
- **Fluid Registration** – Enables **highly flexible deformations**, essential for aligning different individuals.

2. **Probabilistic Atlases**

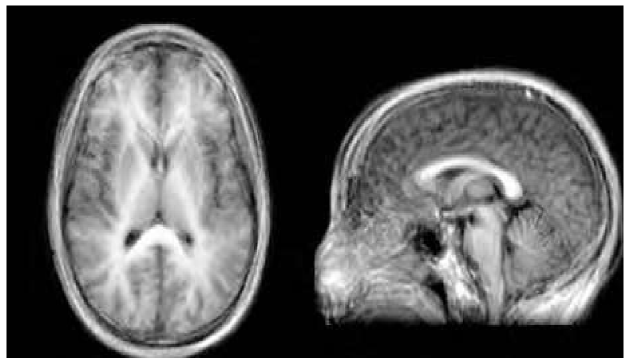
- Combines images from multiple subjects to **better represent population data**.
- Used in **International Consortium for Brain Mapping (ICBM)** for studying brain structure variations.

3. **Statistical Shape Models**

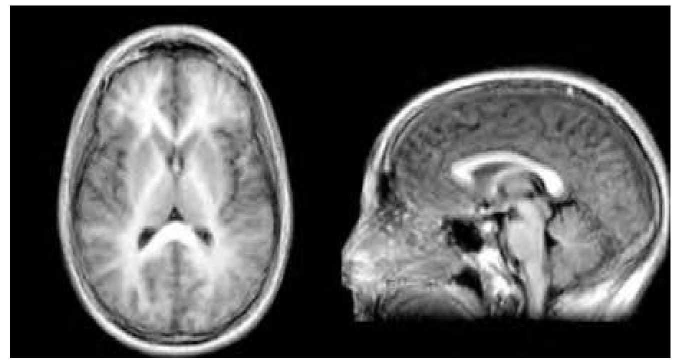
- Helps measure **local and global shape differences** in organs.

Brain Atlas Construction

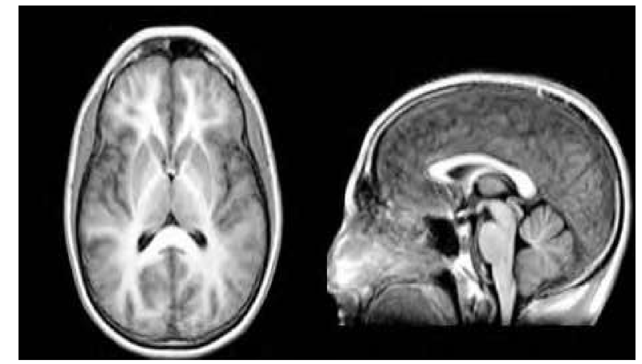
- Seven subjects’ MRI scans were mapped to a reference space.



rigid registration



affine registration



nonrigid registration

- Non-rigid registration produced the most accurate atlas.

Application

- **Brain Atlases & Medical Research** – Standardized brain atlases help researchers compare structural and functional differences between normal and diseased brains. They aid in studying neurological disorders and guiding interventions.
- **Comparing Healthy vs. Diseased Patients** – Techniques like MRI and PET scans help analyze differences in brain morphology and activity in conditions like Alzheimer’s and Multiple Sclerosis. These comparisons assist in early diagnosis and treatment planning.
- **Automated Segmentation & Labeling** – AI-driven segmentation techniques automatically identify and label brain structures, reducing manual effort. This enhances precision in analyzing brain abnormalities and tracking disease progression.

Analysis of Motion and Deformation Using Nonrigid Registration

- It refer to **changes in the shape, position, or structure of organs/tissues** over time.
- Non-rigid registration helps in **tracking and analyzing these changes**.
- **Why is it Important?**

    a. Detects **tumor growth or shrinkage**.

    b. Monitors **organ movement** (e.g., brain shift, heart motion).

    c. Helps in **surgical planning & disease progression analysis**.

Role of Non-Rigid Registration in Motion & Deformation Analysis

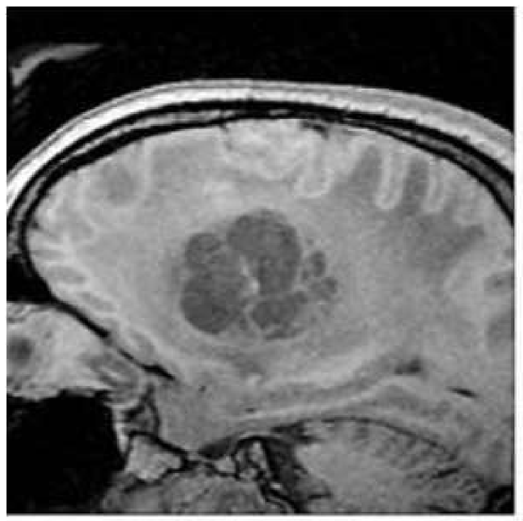
Why Use Non-Rigid Registration?

- **Rigid registration** cannot track soft tissue deformations.
- **Non-rigid registration** provides a **flexible model** to analyze motion & shape changes.
- It helps doctors **quantify how organs/tissues deform over time**.

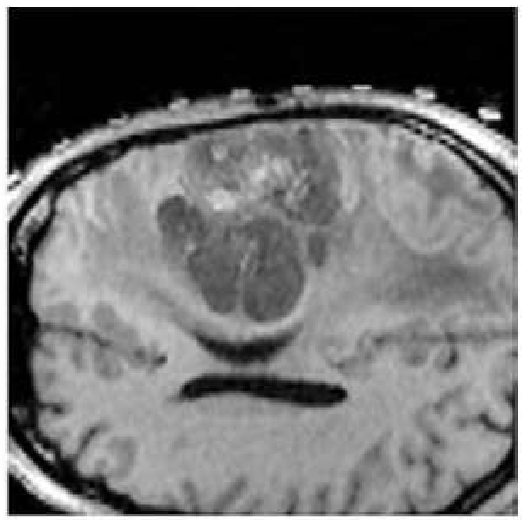
Key Features of Non-Rigid Registration for Motion Analysis:

- **Creates a deformation field** (shows how much a structure has changed).
- **Measures volume & shape changes** (e.g., tumor growth).
- **Aligns pre- and post-surgical images** to track shifts in anatomy.

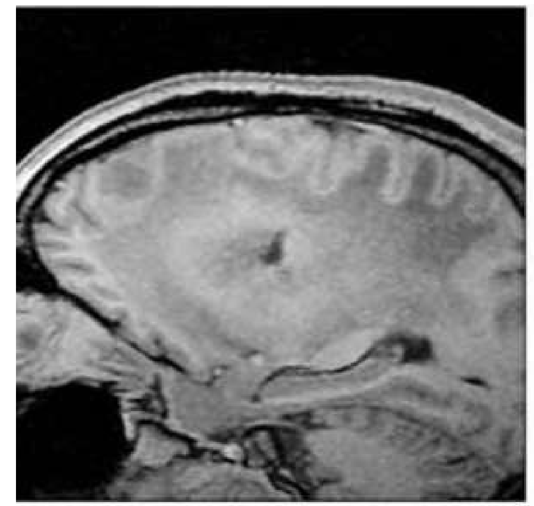
Example: Brain Shift in Surgery



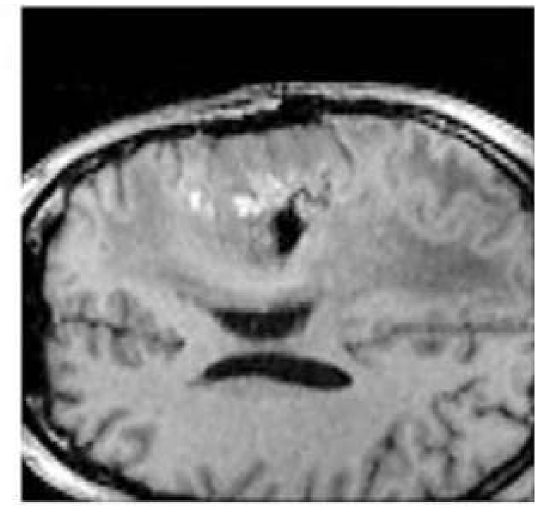
(a)



(b)



(c)



(d)

preoperative MR images

postoperative MR images

Intrasubject Registration

- Intrasubject registration aligns images of the same subject taken at different times or using different imaging modalities.
- Since the human body is non-rigid, simple transformations (like rotation and scaling) are not enough—non-rigid registration is needed to account for tissue deformation.

<u>Techniques Used in Non-Rigid Intrasubject Registration</u>

- B-Spline Free Form Deformation (FFD):
    - Uses a grid of control points to deform the image smoothly.
    - Great for modeling soft tissue deformations.
- Demons Algorithm:
    - Iterative method that updates transformation based on image intensity differences.

Applications

- **Motion Correction in Medical Imaging**
  - Breast MRI (Mammography): Contrast-enhanced breast scans require precise alignment to detect cancer.
  - Cardiac Imaging : Aligns heart images from different cardiac cycles.
- **Preoperative and Postoperative Image Alignment**
  - Neurosurgery: The brain shifts after skull opening, requiring real-time correction.
- **Disease Progression Tracking in Longitudinal Studies**
  - Alzheimer’s Disease: Aligns MRI scans to measure brain atrophy.
  - Tumor Growth Monitoring: Measures how a tumor shrinks or grows.

Example : Contrast Enhanced MRI Mammogı

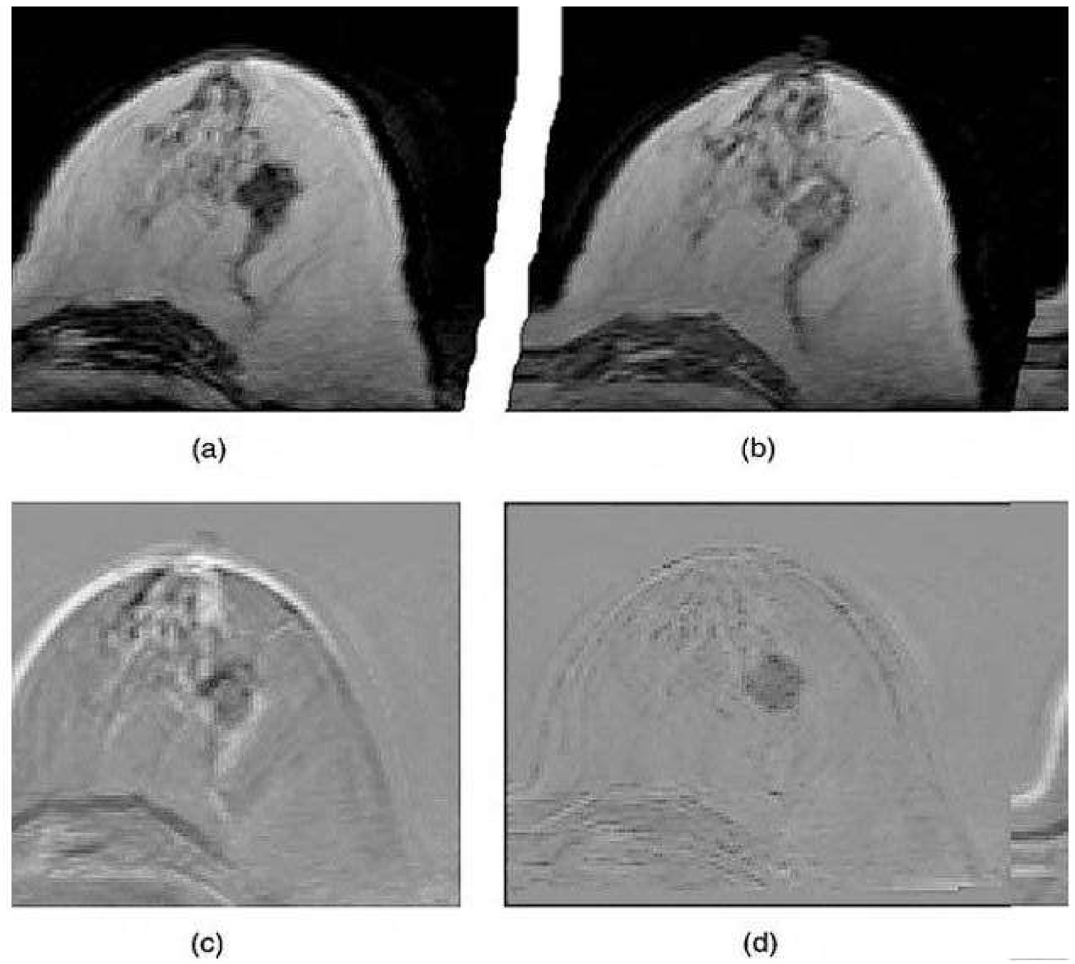


Fig : A contrast-enhanced MR mammography: (a) precontrast, (b) postcontrast and after subtraction (c) without registration, and (d) with nonrigid registration

Conclusion

- **Rigid registration** is widely used, but it cannot handle soft tissue deformations.
- **Non-rigid registration** is essential for tracking anatomical changes in surgery, disease progression, and biomechanics.