



MSc in Digital Humanities
Image Processing/Analysis

Image Registration

(Χωρική Ταύτιση Εικόνων)

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Image Registration

Concept: The process of geometrically aligning two or more images of the same scene.

Purpose: To align corresponding features across multiple images so that they match spatially.

Applications: Used in medical imaging, remote sensing, and computer vision.

Challenge: Images may differ due to viewpoint, scale, rotation, time, or sensor type.

Objective: Establish a **spatial transformation that accurately maps** one image (moving) onto another (fixed).

Importance of Image Registration

Enables: Comparison, integration, and analysis of image data from multiple sources.

Foundation for **key tasks**:

- Image fusion and enhancement
- Object recognition and tracking
- Temporal change detection and monitoring
- Multi-sensor data integration
- Improved interpretation and decision-making

Applications of Image Registration

Geographic Information Systems (GIS):

Aligns maps, aerial photographs, and satellite imagery to support spatial analysis and decision-making.

Example: Combining historical maps with modern satellite data for landscape evolution studies.

3D Technologies:

Integrates multiple 2D images or scans to reconstruct accurate 3D models.

Example: Creating 3D representations of archaeological artifacts from multi-view images.

Data Analytics for Humanities:

Enables comparative analysis of visual and spatial data across time and context.

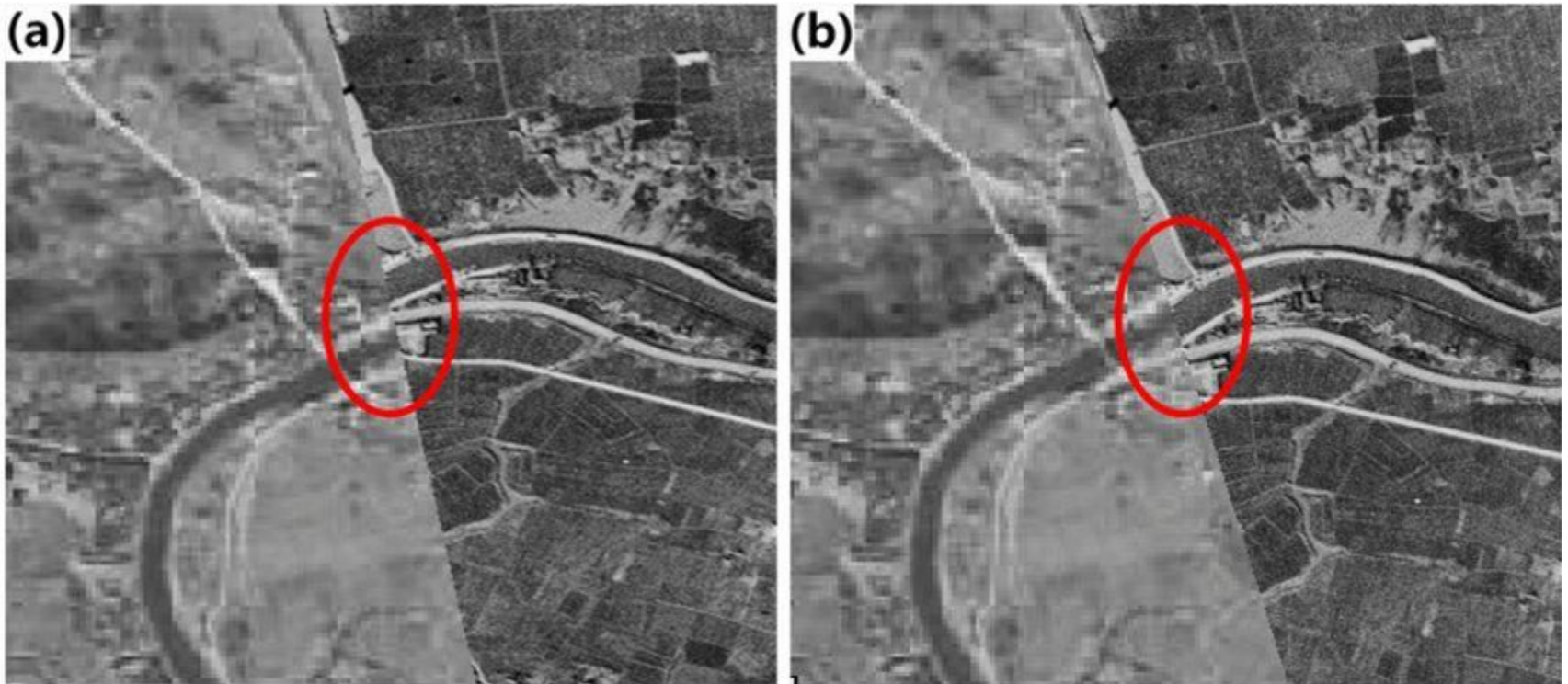
Example: Aligning historical city images to study architectural transformations.

Augmented Textual Studies:

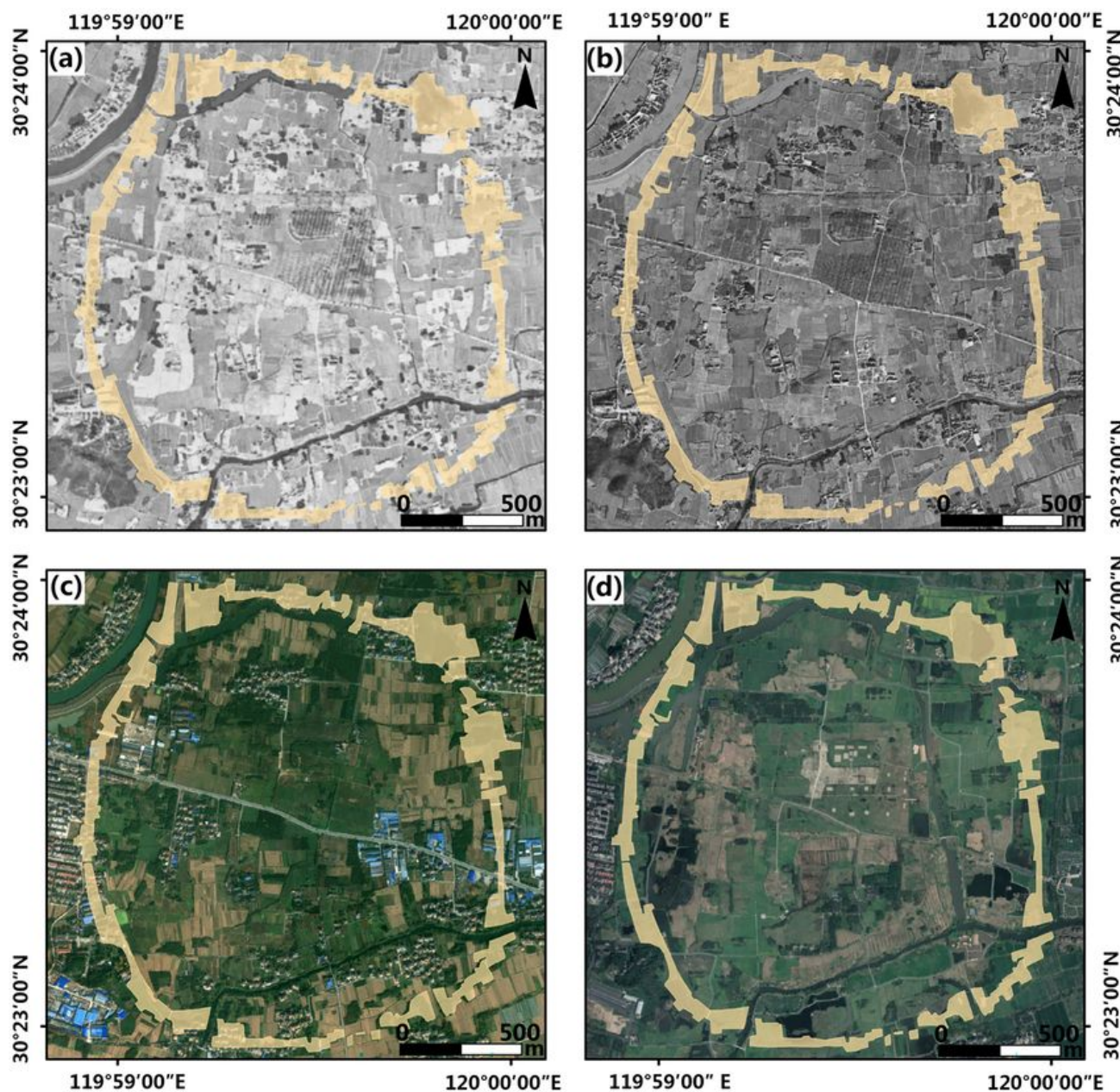
Connects visual and textual sources for enhanced digital scholarship/ for interactive exploration.

Example: Overlaying historical maps with place names from texts.

e.g. Remote sensing images



[Zhang, Yixin & Wang, Ningyuan & He, Jie & Zhang, Tao & Zhang, Xin & Luo, Hongpeng. \(2024\). A convenient archaeological ruins identification method through elevation information extraction from CORONA stereo pairs. Heritage Science. 12. 10.1186/s40494-024-01427-7.](#)

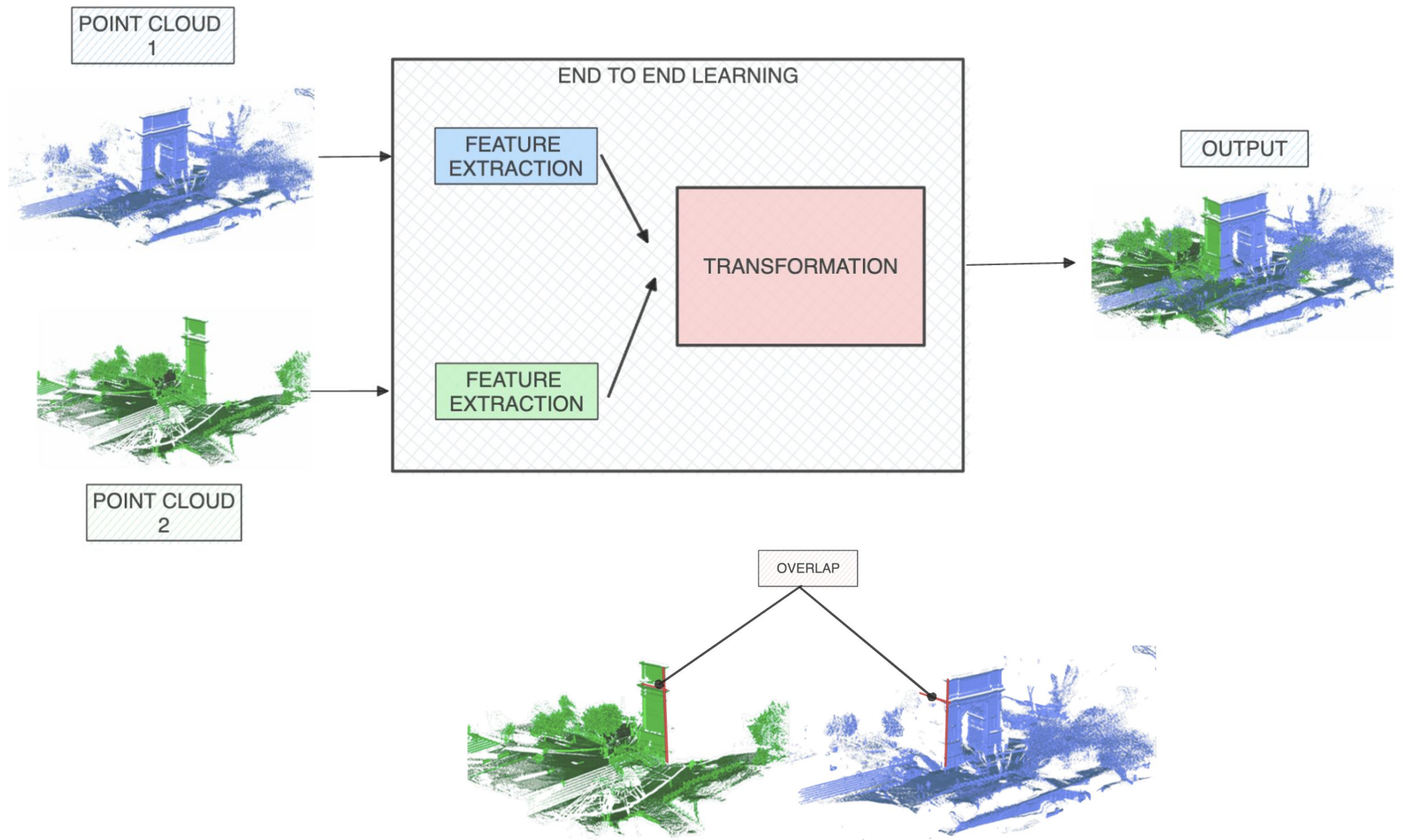


Liangzhu Ancient City in different periods.

The yellow circles represent the walls of Liangzhu Ancient City.

- a. CORONA image photographed in 1968;
- b. photographed in 1972;
- c. photographed in 2010;
- d. photographed in 2022

[Zhang, Yixin & Wang, Ningyuan & He, Jie & Zhang, Tao & Zhang, Xin & Luo, Hongpeng. \(2024\). A convenient archaeological ruins identification method through elevation information extraction from CORONA stereo pairs. Heritage Science. 12. 10.1186/s40494-024-01427-7.](#)



Point Cloud Registration: Beyond the Iterative Closest Point Algorithm

Categories of Image Registration

1. Intra-Modal Registration

Aligns images of the same type or source to ensure consistency.

Examples

- Aligning multiple scans of the same manuscript to compare handwriting or annotations.
- Registering multiple 3D scans from the same sensor to refine a model.
- Matching several high-resolution scans of the same page to enhance readability and detect subtle changes.
- Aligning satellite images from the same sensor over time to monitor environmental changes.

Categories of Image Registration

e.g. Aligning multiple scans of the same manuscript to compare handwriting or annotations.

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M. Diem & M. Lettner & R. Sablatnig / Registration of Ancient Manuscripts

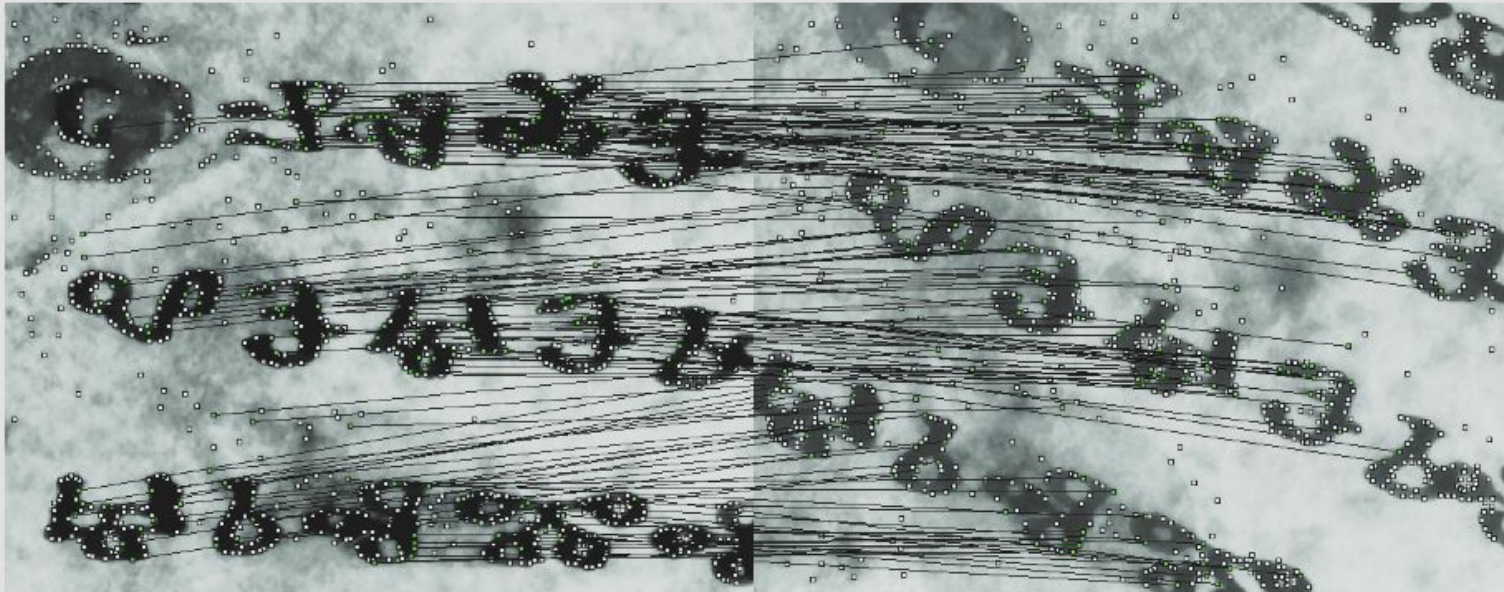


Figure 5: The corresponding control points after the consistency check. The sensed image was rotated about 21° . In contrast to Figure 4, this image contains no wrong correspondences. After the consistency check, 67.6% of the corresponding control points remain.

Categories of Image Registration

2. Inter-Modal Registration

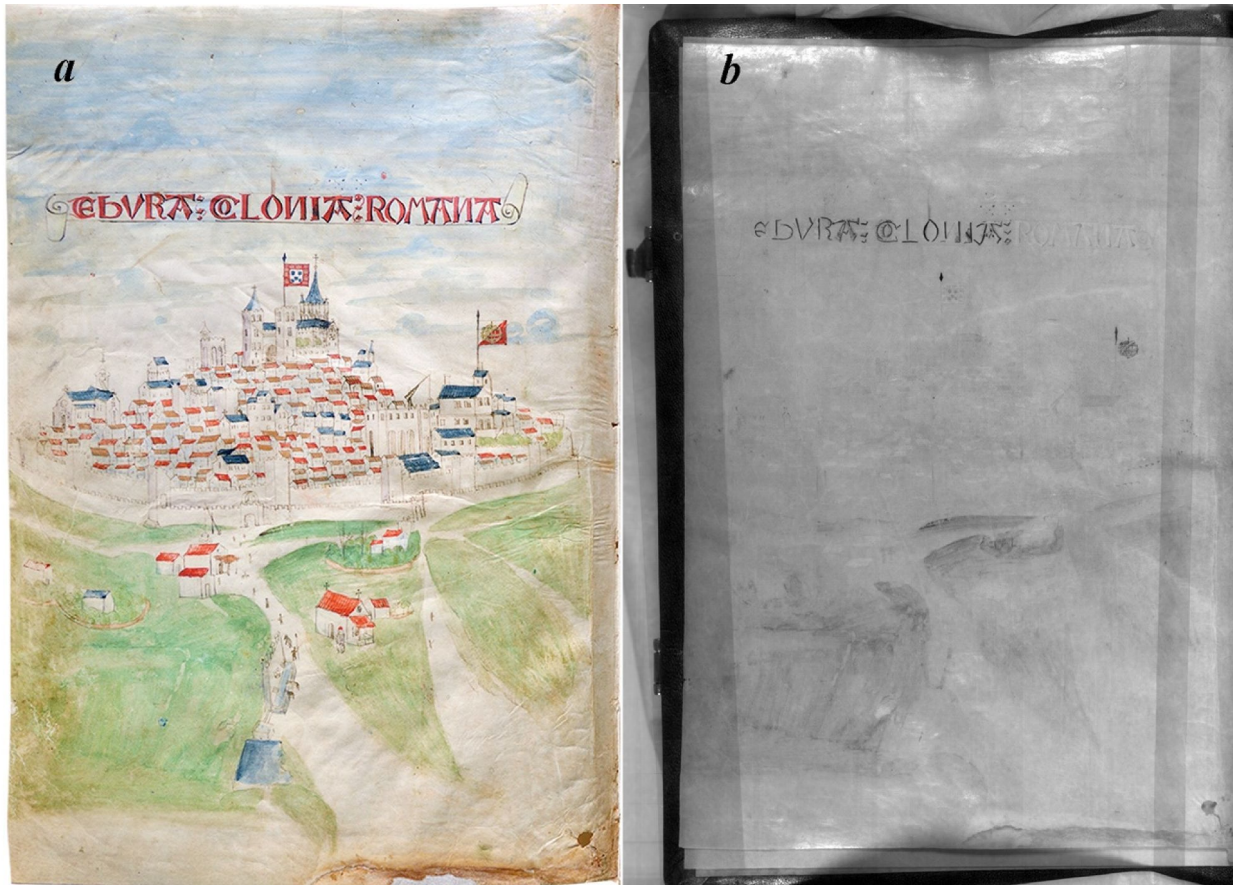
Aligns images from different sources or modalities for integrated analysis.

Examples

- Combining infrared and visible-light scans of manuscripts to reveal hidden text.
- Merging images from RGB cameras with depth sensors to build complete 3D reconstructions.
- Linking manuscript scans with digital transcriptions or annotations for interactive exploration.
- Combining optical imagery with radar or LiDAR data to improve land use mapping and terrain analysis.

Categories of Image Registration

- e.g. Combining infrared and visible-light scans of manuscripts to reveal hidden



Full-size images of the folium presenting the view of the City of Évora in the Charter of Évora:
(a) visible image;
(b) infrared reflectography image.

3. Static vs Dynamic Registration

Static Registration: Aligns pre-captured, fixed images.

- Comparing digitized historical maps or texts.
- Merging pre-scanned 3D models of artifacts.
- Aligning scanned pages with encoded text layers for study.
- Overlaying archived satellite images with maps for historical analysis.

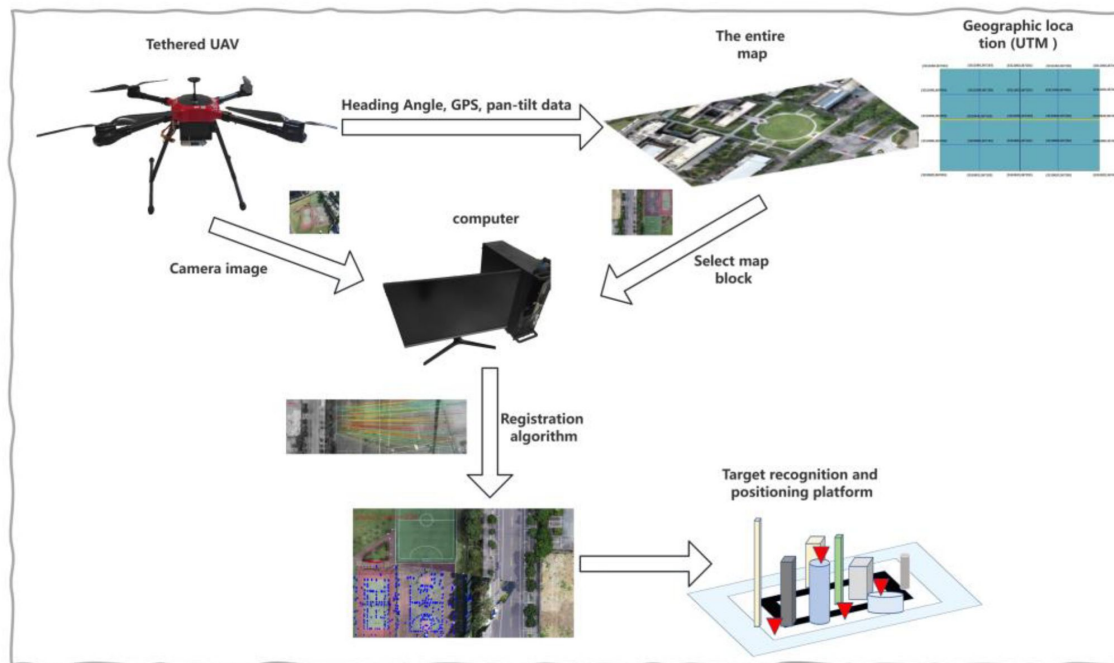


The integration of the 3D models of the structure materials to the photogrammetry-generated 3D model.

3. Static vs Dynamic Registration

Dynamic Registration: Aligns live or continuously captured images in real time.

- Live capture of documents for interactive exhibitions.
- Real-time 3D reconstruction during scanning or motion capture.
- Overlaying digital annotations on live manuscript camera feeds for interactive learning.
- Real-time alignment of UAV/drone imagery for disaster monitoring or urban mapping.



Key Concepts

Fixed Image - Moving Image

- Fixed Image:
 - The reference image that remains unchanged.
 - It provides the coordinate space to which the moving image is aligned
 - Example: A high-resolution scan of a medieval manuscript page captured initially.
- Moving Image:
 - The image that is transformed during the registration process to align with the fixed image
 - Example: An infrared or ultraviolet scan of the same page to reveal hidden text or annotations.

Use: Aligning multiple scans to compare handwriting, annotations, or under-text across different captures.

Registration as an Optimization Problem

The main goal in **image registration** is to find the **transformation $\mathbf{v}$** that minimizes the **cost function C** .

The process is iterative:

- The optimizer updates the **transformation $\mathbf{v}$** at each iteration.
- Iterations continue until the best alignment is achieved (**local minimum**).

The Three Fundamental Components of Registration

Transformation Model:

- Defines the type of spatial changes allowed (Rigid, Affine, Non-Rigid (Deformable)).
- Determines how the moving image can be shifted, rotated, or deformed to align with the fixed image.

Similarity Cost Function:

- Measures how well the images match each other.

Can use metrics like Mean Squared Error, Mutual Information, Cross-Correlation.

Optimizer:

- Searches for the optimal transformation that minimizes the cost function.

Can use methods like Gradient Descent, Evolutionary Algorithms, or other search techniques.

The combined operation of these three components is crucial for successful image registration.

Fundamental Component: Transformation Models

1. Rigid Transformation

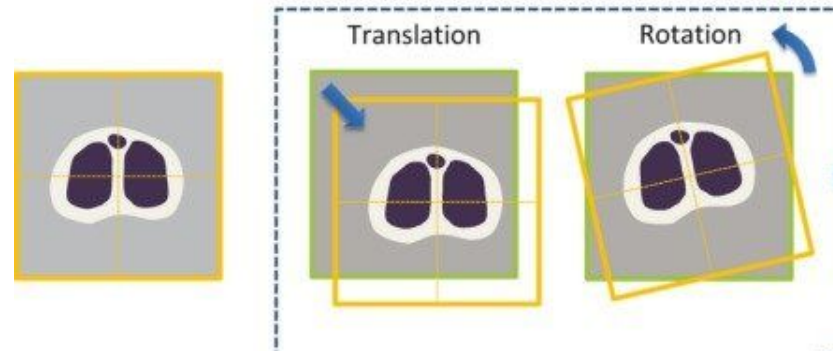
Operations: Translation (shifting), Rotation

Characteristics: Maintains original distances and angles; no stretching or distortion.

Best for scenarios where the objects are unchanged in size or shape; only position or orientation differs.

Examples:

- Slightly rotated or shifted scans of the same manuscript page.
- Rotating a 3D scan of an artifact to match another viewpoint.
- Translating and rotating a satellite image to roughly match a reference map.



Fundamental Component: Transformation Models

2. Affine Transformation

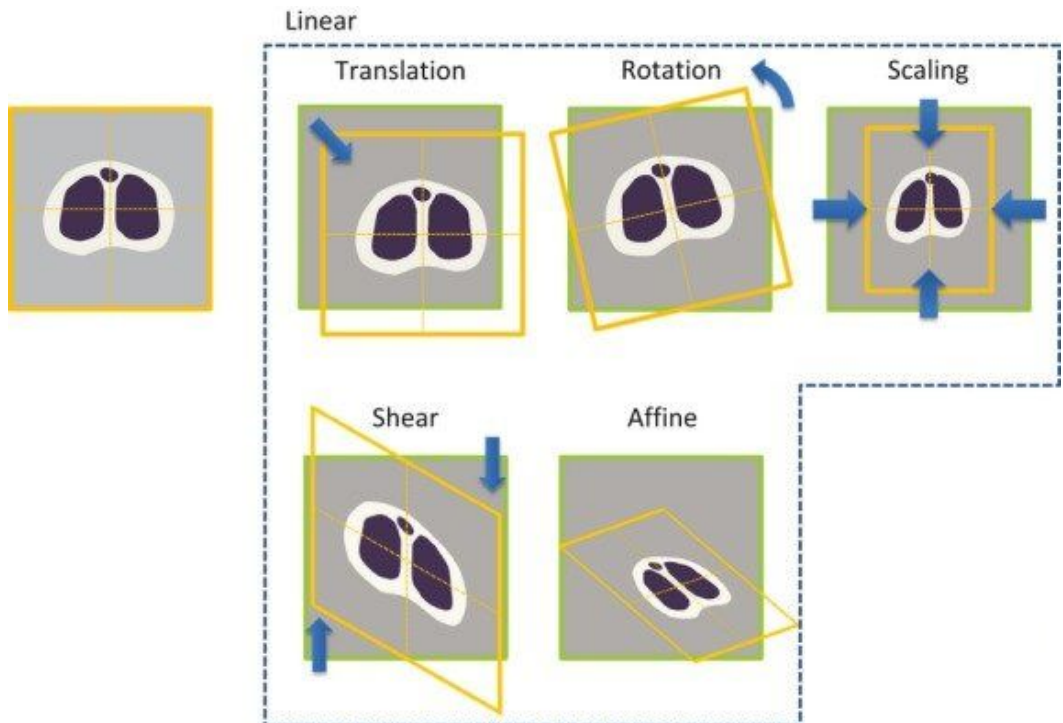
Operations: Translation, Rotation, Scaling, Shearing

Characteristics: Preserves straight lines and parallelism but allows scaling and shearing

Useful when images are captured under different scales or slightly skewed perspectives. Maintains overall structural relationships while correcting linear distortions.

Examples:

- Aligning a historical map with a modern reference grid.
- Adjusting a 3D building scan to fit a scaled reference model.
- Aligning scanned manuscript pages with digital transcription layers, accounting for skew or scale differences.



Fundamental Component: Transformation Models

3. Non-Rigid (Deformable) Transformation

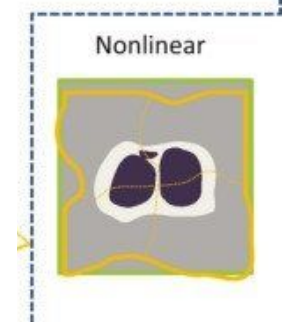
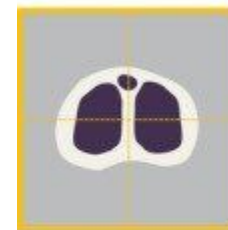
Operations: Local deformations in addition to global transformations.

Characteristics: Allows stretching, bending, or warping of regions to achieve precise alignment.

Essential when images or objects undergo shape changes or distortions, such as flexible surfaces, soft tissues, or warped documents. Perfect for fine-grained registration.

Examples:

- Correcting warped manuscript pages caused by folds or age-related shrinkage.
- Adjusting scans of flexible objects, fabrics, or sculptures to align perfectly.
- Aligning LiDAR terrain models with satellite imagery, compensating for sensor or terrain distortions.



Fundamental Component: Transformation Models

Goal: Find the transformation that best aligns the moving image to the fixed image.

Common estimation methods:

- **Feature-based:** Uses keypoints, edges, corners; matches features between images.
- **Intensity-based:** Optimizes a similarity metric (MSE, MI, CC) over pixel values.
- **Hybrid:** Combines feature matching and intensity optimization for robust results.

Workflow

1. Detect features / initialize alignment.
2. Compute similarity or error metric.
3. Iteratively update transformation until convergence.

Fundamental Component: Similarity Cost Function

- Measures how well the moving image aligns with the fixed image.
- Provides a quantitative score for alignment quality.
- Crucial for both feature-based and intensity-based registration.
- Guides the optimizer in finding the best transformation.

Common Similarity Metrics

- **Mean Squared Error (MSE):** Measures intensity differences between images.
- **Mutual Information (MI):** Measures statistical dependency between images; works for multimodal images.
- **Cross-Correlation (CC):** Measures linear relationship between image intensities.
- **Other metrics:** Normalized Cross-Correlation, Correlation Ratio.

Choosing a Similarity Metric

- Depends on image modality: same vs. different modalities (e.g., LiDAR & vector files).
- Feature vs. intensity-based registration influences choice.
- Good metric ensures robust and accurate alignment.
- Often combined with preprocessing or masking to improve performance.

Fundamental Component: Optimizer

Core component in all image registration methods.

- **Purpose:** Finds the best transformation to align images accurately.
- **Process:** Updates the moving image step by step to reduce misalignment.
- **Goal:** Achieve the closest match between fixed and moving images.

Methods categories

- **Gradient-Based Methods :** Uses the slope (derivative) of the cost function to guide adjustments.
 - e.g. Gradient Descent, Conjugate Gradient.
 - (+) Fast and effective when images are already roughly aligned.
 - (-) Can get stuck in local solutions if starting point is poor.
- **Evolutionary and Global Search Methods:** Explores many possible transformations across the image space.
 - e.g. Genetic Algorithms, Particle Swarm Optimization.
 - (+) Can handle complex images and large misalignments.
 - (-) Trade-off: Slower than gradient methods but more robust to difficult cases.

Fundamental Component: Optimizer

Choosing the Right Optimizer

- **Factors:** Image type, complexity, and computing resources.
- **Strategy:**
 - a. Use gradient-based methods for simple, smooth alignments.
 - b. Use global search for highly deformable or multimodal images.
 - c. Combine both for fast initial search, then fine-tune (Hybrid approaches).

Resources

1. [Multispectral Imaging and Microscopic Analysis of a Medieval Runic Manuscript \(AM 28 8vo\) | Digital Medievalist](#)
2. [A Registration Method for Historical Maps Based on Self-Supervised Feature Matching](#)
3. <https://www.sciencedirect.com/science/chapter/monograph/pii/B9780124059061000040>