High-resolution multimodal image registration of Théo van Rysselberghe's *La dame en blanc (1904)* using mutual information.

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Introduction

Multimodal imaging techniques—including high-resolution photography under visible and ultraviolet light (UV), infrared reflectography (IRR), X-ray radiography (XRR), hyperspectral imaging (HSI), and macro-X-ray fluorescence (MA-XRF)—are essential for studying a painting's material composition, hidden features, and conservation needs. However, comparing these multimodal images poses challenges due to resolution mismatches, reconstruction-induced deformations, and gigapixel-scale data. A two-step registration using mutual information and the *Insight Segmentation and Registration Toolkit* (ITK) [1] was developed to address these issues. Initially, an affine transformation achieves coarse alignment, followed by a refined B-spline transformation. Both steps use a pyramidal approach at multiple scales with an L-BFGS-B optimizer maximizing mutual information between images. Images are rescaled and aligned to a common high-resolution visible-light photograph reference. Registered images are tiled with Photoshop's Zoomable plugin [2] and displayed in a custom viewer, facilitating smooth multimodal navigation. This method was applied successfully to Théo van Rysselberghe's *La dame en blanc* (1904) [3], belonging to the collection of Liège's Museum of Fine Arts.

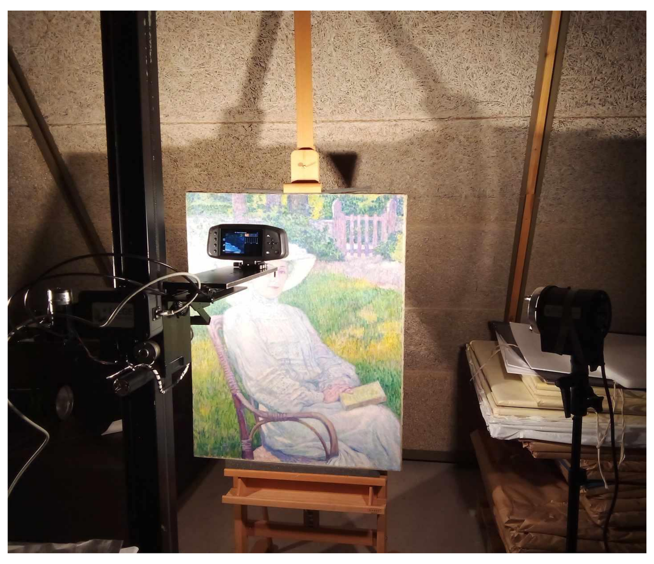

Fig. 1: Setup for the capture device.

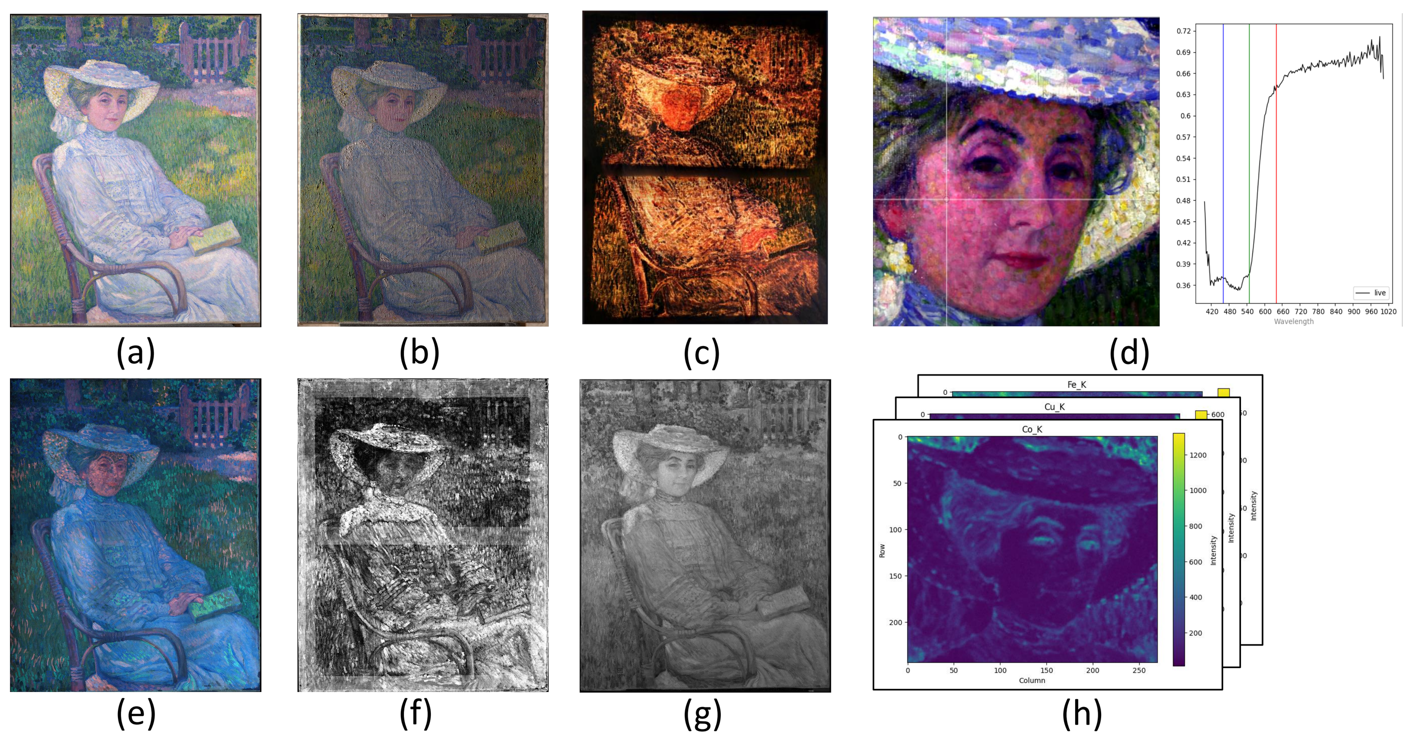

Fig. 2: Imaging data: (a) visible light (front), (b) visible raking light, (c) transmitted light, (d) HSI, (e) UV, (f) XRR, (g) IRR, (h) MA-XRF.

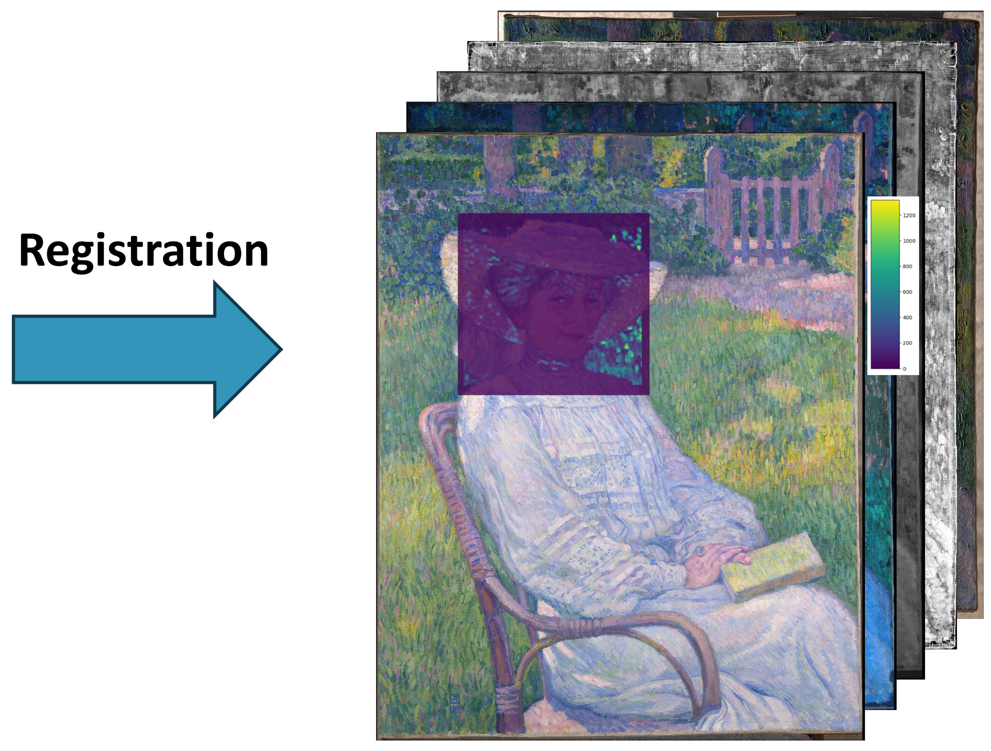

Fig. 3: Registered data-cube

Challenges

Each modality is captured as an overlapping mosaic using a motorized XY rail. The system records dozens of local tiles, which are later stitched into gigapixel panoramas.

Resulting challenges :

- Gigapixel file sizes strains memory & processing capacity.
- Native spatial resolutions differ between modalities.
- Local distortions arise from lens aberrations, rail vibrations, misalignment of the capture device, and stitching artifacts.

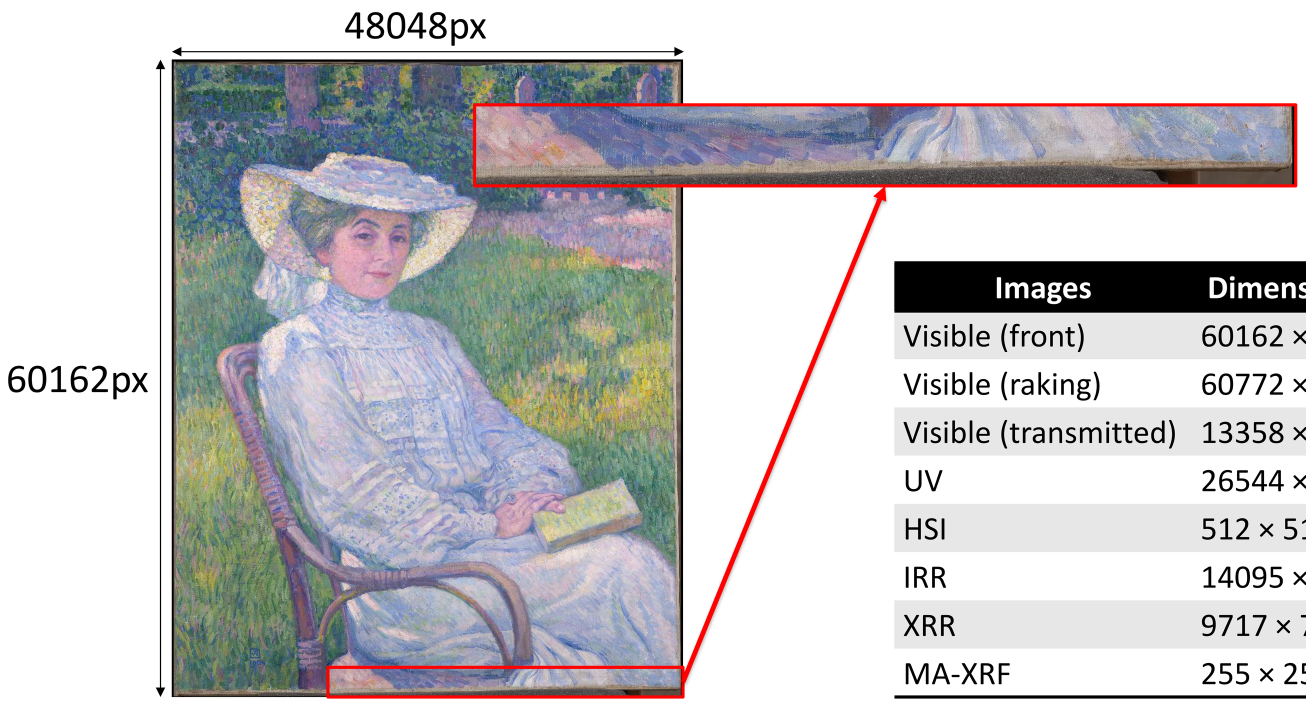

Fig. 4: High-resolution visible image (60162×48048px) of *La dame en blanc* [3] used as the reference for multimodal registration. The image presents a deformation at the bottom.

Images	Dimensions (pixels)
Visible (front)	60162 × 48048
Visible (raking)	60772 × 48332
Visible (transmitted)	13358 × 10376
UV	26544 × 20777
HSI	512 × 512
IRR	14095 × 11617
XRR	9717 × 7744
MA-XRF	255 × 255

Tab. 1: Images dimensions

Results

The registered images were tiled using Photoshop's Zoomable plugin [2] to create multi-resolution image pyramids. These were then integrated into a custom web-based viewer built with the OpenSeadragon library [5], enabling smooth zooming, panning, and side-by-side or overlay comparison of the multimodal data-cube. The pixels on the 2D histogram are also concentrated along the diagonal, indicating a much better correlation.

Before registration

After registration

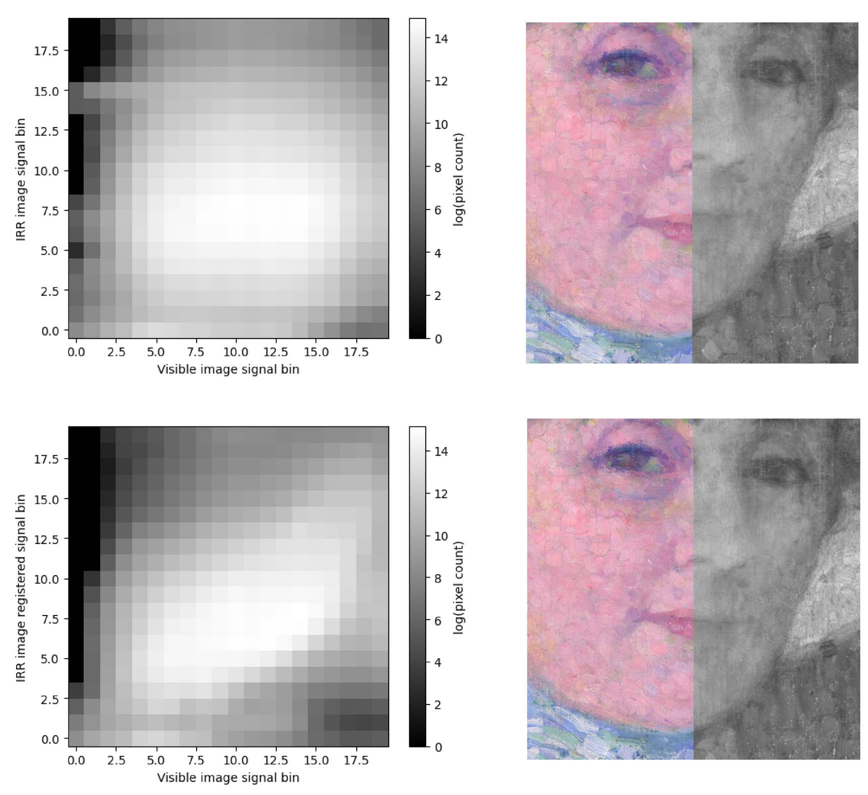

Fig. 6: Registration results for the IRR image. Left: joint intensity histograms before registration (top) and after registration (bottom), showing increased correlation between images. Right: close-up of the face region before (top) and after (bottom) registration.

Registration Process

The registration was performed with the ITK library [1] using a two-stage strategy. Because the images are multimodal, the metric used for assessing the image alignment is the **mutual information**:

$$MI(X;Y) = \sum_{x \in X} \sum_{y \in Y} P(X=x, Y=y) \log\left(\frac{P(X=x, Y=y)}{P(X=x) \cdot P(Y=y)}\right)$$

Mutual information was chosen because it measures shared information content between images, rather than relying on pixel intensity similarity. This makes it well-suited for evaluating alignment across different imaging modalities [4].

Registration steps:

1. **Coarse affine registration:** a six-parameter affine matrix (translations, rotations, scale, shear) is optimized with the L-BFGS-B variant of gradient descent to maximize mutual information between the moving and reference images. A multi-resolution pyramid (coarse → fine) cuts computation time and avoids local minima.

$$T(x) = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} x + \begin{bmatrix} t_x \\ t_y \end{bmatrix}$$

2. **Non-rigid registration:** residual distortions are corrected with a B-spline model. A regular grid of control points is laid over the moving image. Each point carries a displacement vector that the optimizer updates to warp the image smoothly.

$$T(x) = x + \sum_{x_k \in N_x} p_k \beta^3\left(\frac{x - x_k}{\sigma}\right)$$

- $\beta^3(x)$: the cubic multidimensional B-spline function
- σ: grid spacing
- p_k: the B-spline coefficient vectors
- N_x: set of control points

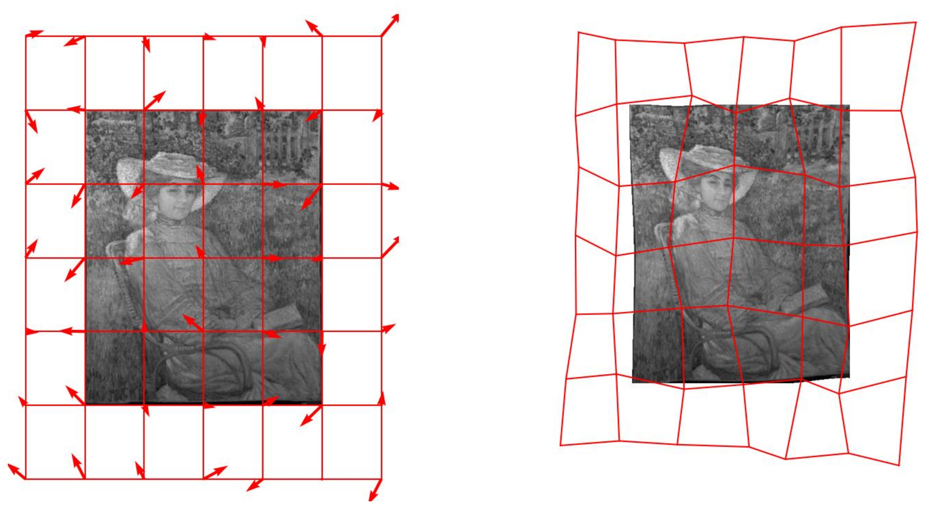

Fig. 5: Illustration of the B-spline transformation.

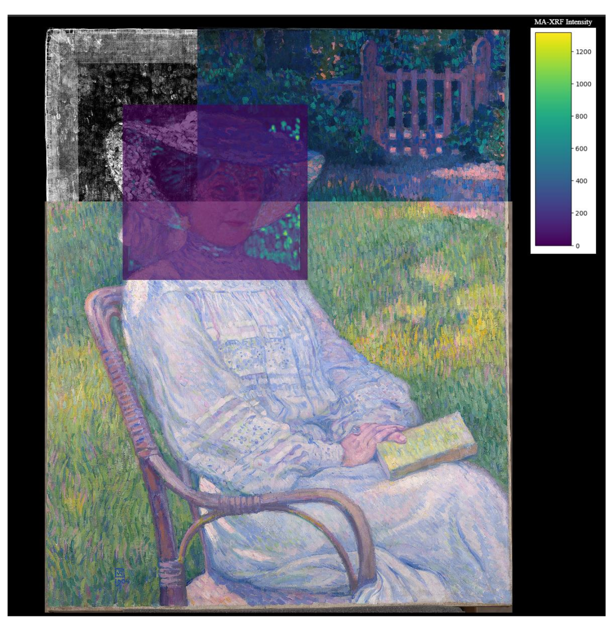

Fig. 7: Custom viewer showing XRR, UV, MA-XRF, and visible data together.

Conclusion

Accurate multimodal registration was achieved by aligning all image modalities to a high-resolution visible-light photograph, ensuring spatial correspondence. The registered images were integrated into a custom viewer for smooth, interactive exploration.

Next steps:

- Integrate HSI and MA-XRF spectral data-cubes into the viewer for simultaneous inspection of raw spectra and high-resolution images.
- Fuse HSI–MA-XRF data for machine learning–based pigment identification and precise spatial mapping.

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References

[1] Bradley C. Lowekamp, David T. Chen, Luis Ibanez, et Daniel Blezek. 2013. "The Design of SimpleITK." Frontiers in Neuroinformatics 7. https://doi.org/10.3389/fninf.2013.00045.
[2] Adobe Systems. 2024. Adobe Photoshop 2024, with Zoomify Export Plugin. San Jose, CA: Adobe Systems. https://www.adobe.com/
[3] Théo van Rysselberghe. 1904. *La dame en blanc*. Oil on canvas, 92.5 × 73 cm. Museum of Fine Arts of Liège (La Boverie), Inventory No. 306.
[4] Maria Eugenia Villafane, Nathan Daly, Christine Kimbriel, Catherine Higgitt, and Pier Luigi Dragotti. 2023. "Multimodal Image Registration and Mosaicking of Artworks: An Approach Based on Mutual Information." Optics for Arts, Architecture, and Archaeology (O3A) IX, vol. 12620, 21–38. Bellingham, WA: SPIE. https://doi.org/10.1117/12.2673427.
[5] OpenSeadragon. 2024. OpenSeadragon: An Open-Source JavaScript Viewer for High-Resolution Zoomable Images. https://openseadragon.github.io/.