## Supplementary Materials

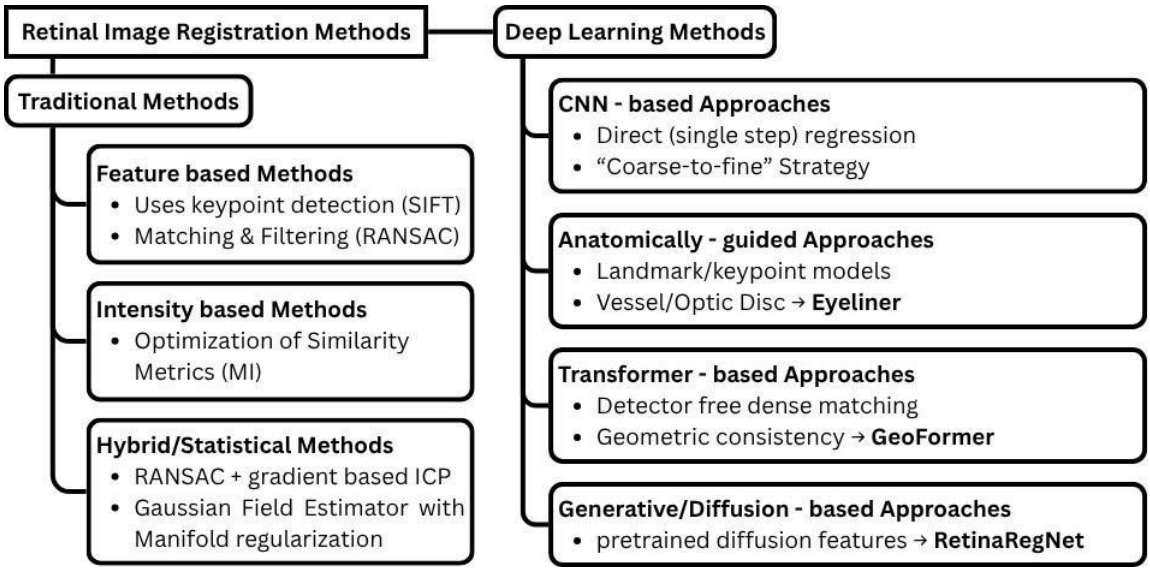


**Figure S1.** Taxonomy of retinal image registration methods. The field can be broadly divided into two main families: **Traditional methods** and **Deep Learning methods**

**Supplementary Table 1 -** Comparison of Architectural Components Across Key Stages of Retinal Image Registration Methods

| | **RetinaRegNet** | **EyeLiner** | **GeoFormer** |
|---|---|---|---|
| Keypoint selection | SIFT + random sampling | SuperPoint + anatomy guided filtering | - |
| Keypoint matching | Dense 2D correlation on diffusion feature map | LightGlue | Attention mechanism |
| Match outlier removal | Inverse consistency + geometric transformation consistency | - | RANSAC + confidence thresholding + geometric locality constraint |
| Image warping | Homography global transformation + 3rd order polynomial local transformation | Affine global transformation + constrained local deformation | Homography transformation |

**Supplementary Table 1** presents the four key stages in image registration, namely keypoint selection, keypoint matching, match outlier removal, and image warping, and the techniques applied by the three methods at each stage.

**Supplementary Table 2** Parameter configuration – Eyeliner

| **Parameter** | **Value used** | **Role** |
|---|---|---|
| Image size (-s) | 256 | Processing resolution |
| TPS lambda (-l) | 1 | Smoothness–flexibility trade-off |
| Keypoint source | detected / manual | Automatic vs ground-truth landmarks |
| Registration params field (-r) | specified | Controls warping configuration |
| Device | cuda:0 | Hardware acceleration (runtime only) |

**Supplementary Table 3** Parameter configuration – GeoFormer

| **Parameter** | **Value used** | **Role** |
|---|---|---|
| Image size (imsize) | 768 | Input resolution |
| Match threshold | 0.2 | Feature correspondence filtering |
| RANSAC threshold | 15 px | Geometric verification tolerance |
| No-match upscale | True | Behaviour when no matches found |

**Supplementary Table 4** – Parameter Configuration - RetinaRegnet

| Parameter | Value used | Role |
|---|---|---|
| Input image size (img_size) | 920 | Registration resolution |
| Processing size (img_shape) | 256 | Internal model resolution |
| Number of keypoints (N) | 50 | Landmark density |
| Min keypoint distance (max_dist) | 5 | Spatial separation constraint |
| Edge exclusion offset | 0.01 | Removes boundary artefacts |
| Diffusion timestep | 75 | Feature extraction scale |
| U-Net feature level | 1 | Feature abstraction depth |
| ICCL level | 3 | Feature correlation strength |
| Multi-resolution iterations | 3 | Refinement depth |
| Outlier model | affine | Landmark filtering model |
| Outlier threshold | 20 px | Error tolerance |
| Success threshold | 12.5 px | Evaluation criterion |
| Max threshold | 25 px | Upper bound for success curves |

**Supplementary Table 5.** Computational complexity analysis for each processing stage of the three retinal image registration methods.

| **Processing Stage** | **RetinaRegNet** | **EyeLiner** | **GeoFormer** |
|---|---|---|---|
| Feature Extraction | $O(N^2)$ for diffusion forward pass on $M \times M$ images; computationally expensive due to U-Net architecture depth | $O(N^2)$ for vessel segmentation; moderate complexity depending on segmentation network architecture | $O(N^2)$ for CNN backbone + $O(N^2 \log N)$ for transformer attention; moderate complexity |
| Correspondence Computation | $O(L^2 \times M^2)$ for dense correlation matrix; $L = 2000$ keypoints, exponential scaling with feature density | $O(K^2)$ where $K$ is number of detected vessel landmarks; typically $K \ll L$, more efficient | $O(N^2)$ for coarse matching + $O(M^2)$ for fine matching; efficient due to coarse-to-fine strategy |
| Outlier Detection | $O(L \times I)$ where $I$ is iteration count for two stage filtering; sequential processing reduces computational burden | $O(K)$ for anatomical constraint checking; linear complexity in landmark count | $O(C \times I)$ where $C$ is correspondence count and $I$ is RANSAC iterations; single-stage complexity |
| Transformation Estimation | $O(L^3)$ for least-squares solving with $L$ correspondences; | $O(K^3)$ for transformation fitting; generally, $K$ | $O(C^3)$ for homography estimation; |

| | | | |
|---|---|---|---|
| | polynomial complexity | $\ll L$ reduces computational load | standard complexity |

**Supplementary Table 5** presents the computational complexity analysis for each processing stage of the three retinal image registration methods, showing how algorithmic choices impact scalability and processing efficiency.