An Experimental Evaluation of the Accuracy of Keypoints-based Retinal Image Registration

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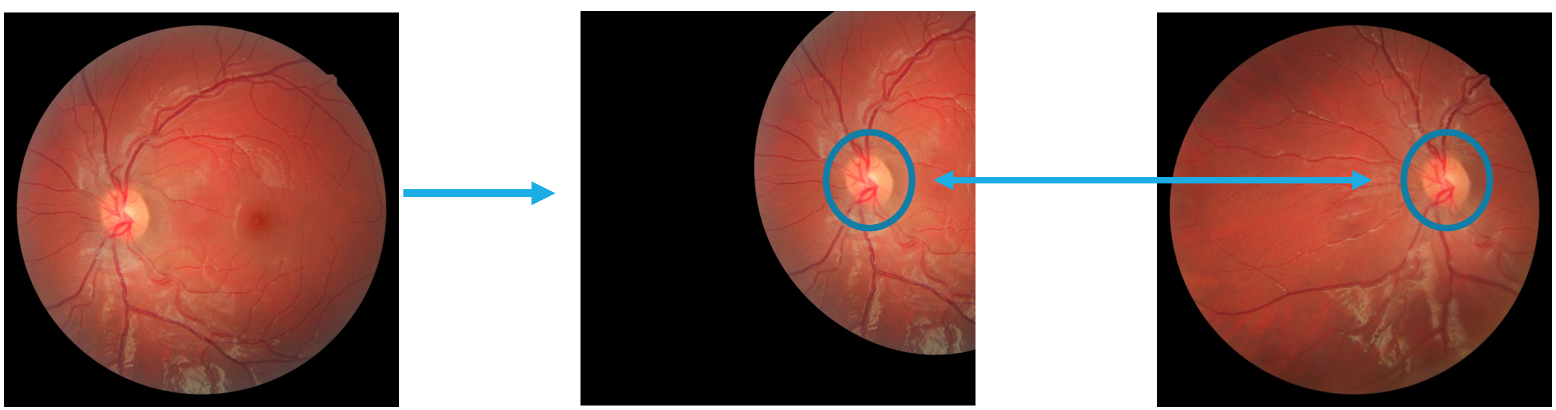
What is image registration?

Image registration involves **a pair of images**: reference and test.

It consists on transforming the **test** image so both images are aligned in the **reference** image **frame.**

This is done by utilizing the **common information** in both images**.**

Retinal image registration consists on the registration of **retinal images**.



Test image — Transformed test image — Reference image

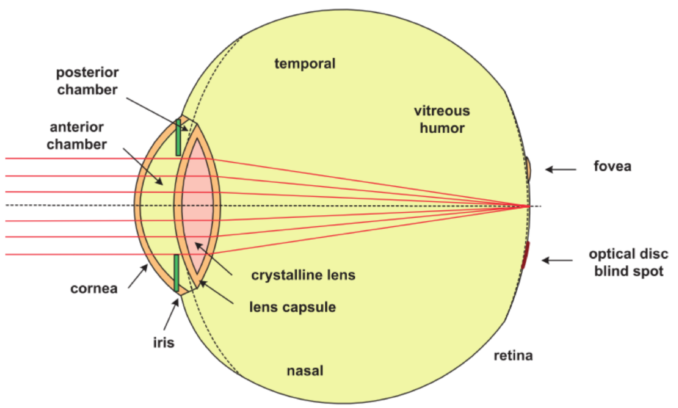
Why is it important?

Analyzing **small vessels** promotes **diagnosis** and **disease monitoring**

The **retina** allows to **directly** observe the microvasculature of the eye

Comparative **analysis** is **facilitated** by retinal image **registration**

Additionally, registration **supports** a range of **applications**



[Gross 2008]

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REMPE framework

Geometrical approach

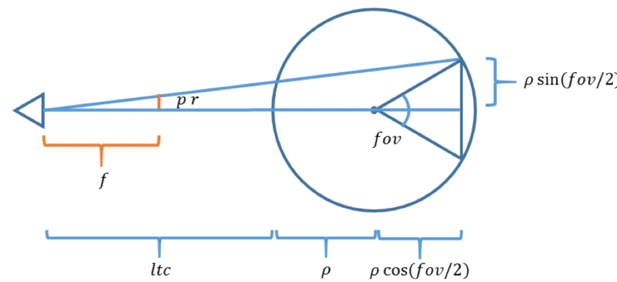
Simultaneously estimate relative **camera pose** and **eye shape** and **orientation**

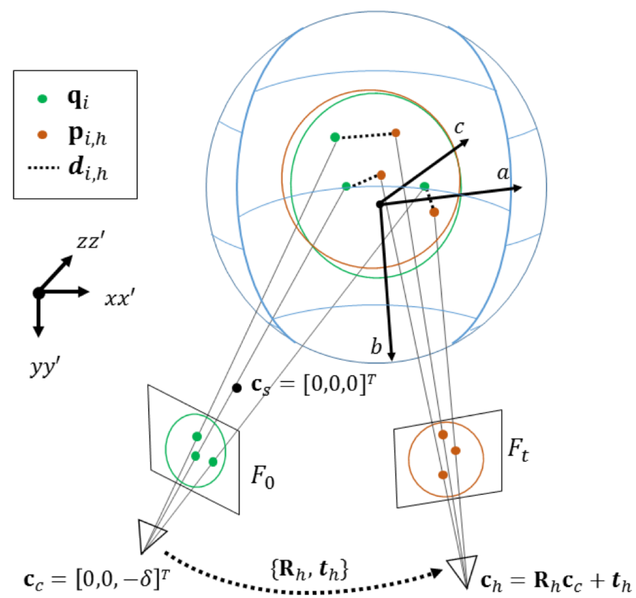
Project points from hypothetical cameras to an eye **model**

Distance of points in model should be **0**

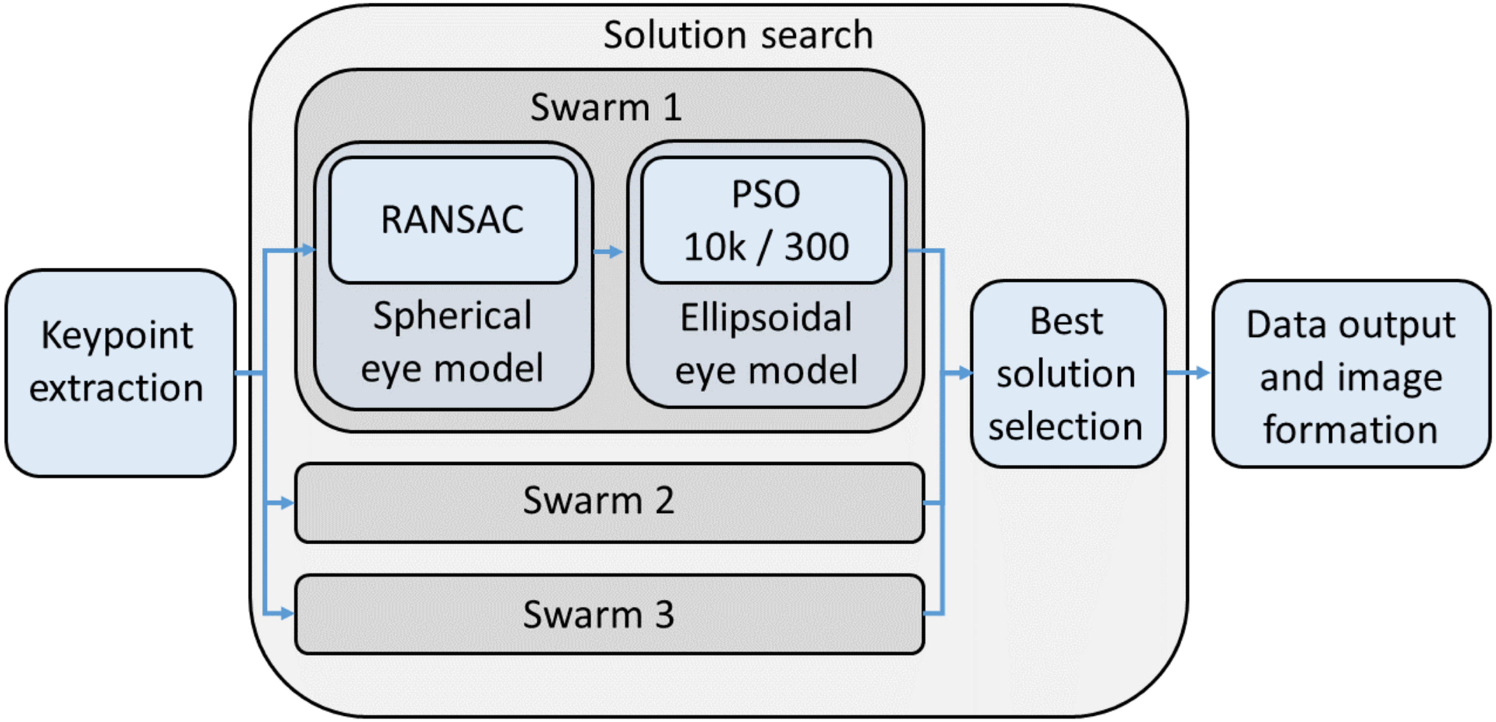
Solution is represented via 12 parameters, divided in 4 groups:

- **R:** $[r_x, r_y, r_z]$
- **t:** $[t_x, t_y, t_z]$
- **A:** $[a, b, c]$
- **Q:** $[r_a, r_b, r_c]$

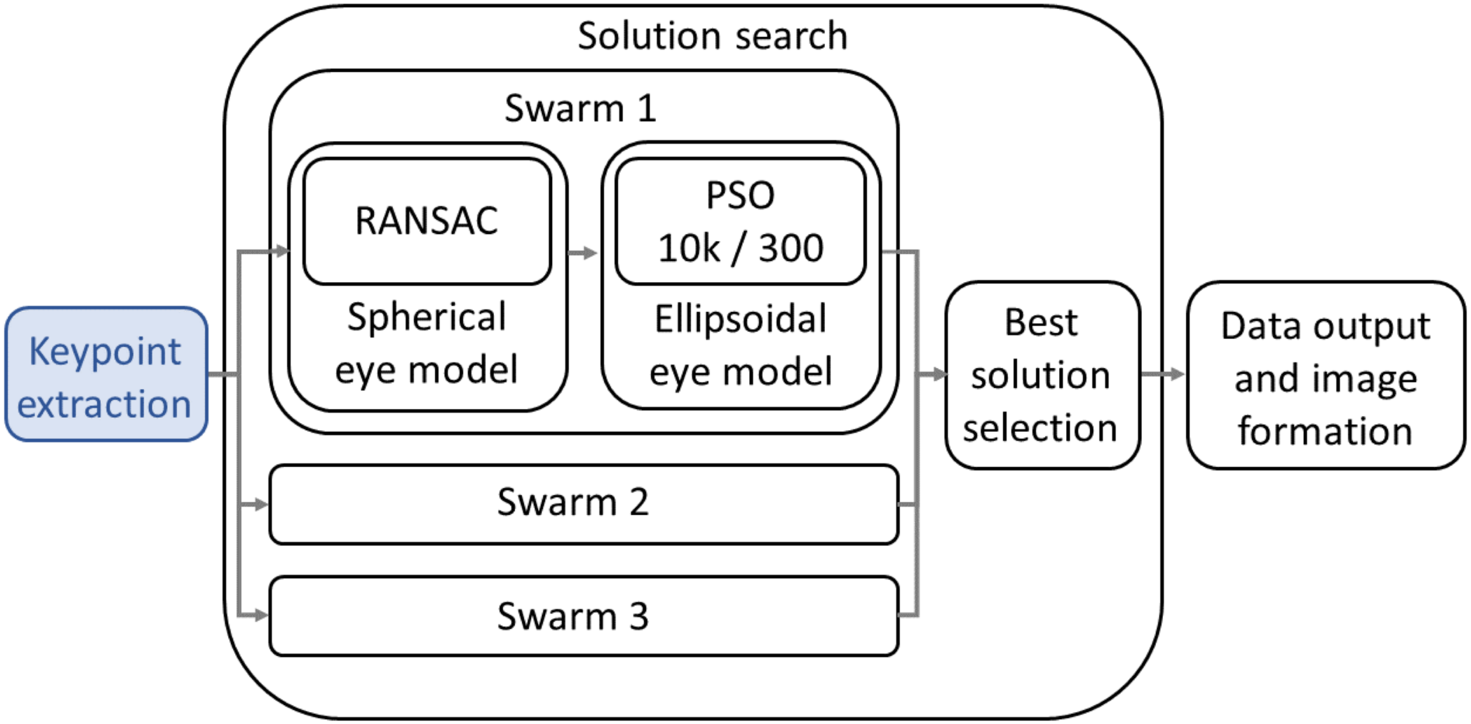




REMPE framework



Keypoints



Solution search
Swarm 1
RANSAC
Spherical eye model
PSO
10k / 300
Ellipsoidal eye model
Keypoint extraction
Best solution selection
Data output and image formation
Swarm 2
Swarm 3

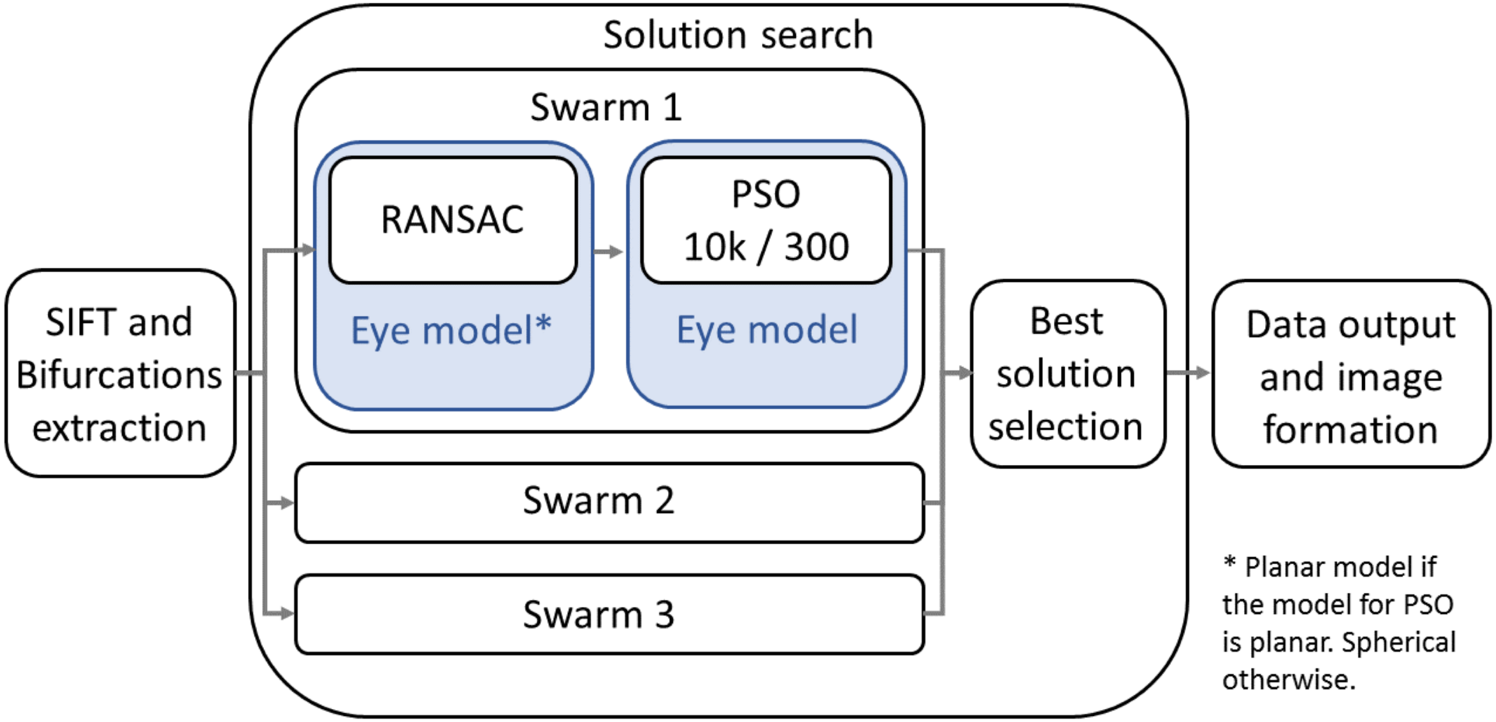
Keypoints

Keypoints are used to identify common points in the pair of images

Four types of keypoints and their combinations are studied

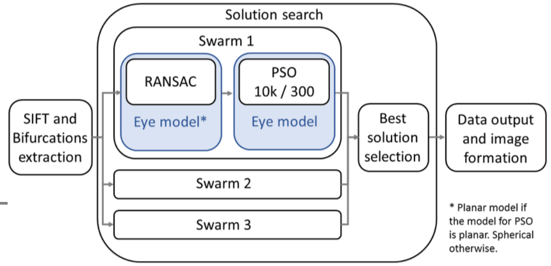
- **SIFT** [Lowe 2004]: milestone method in extracting characteristic points in images.
- **SURF** [Bay 2008]: is another widely used method to detect and represent keypoints.
- **Harris-PIIFD** [Chen 2010]: Partial Intensity Invariant Feature Detector on Harris corners. Developed specifically for retinal image registration.
- **Vessel bifurcations**: Bifurcations on the vessel tree are extracted.

Eye model



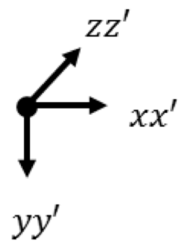
* Planar model if the model for PSO is planar. Spherical otherwise.

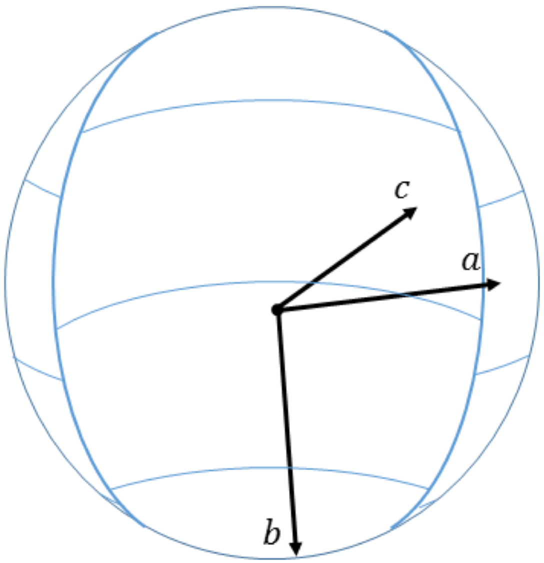
Eye model



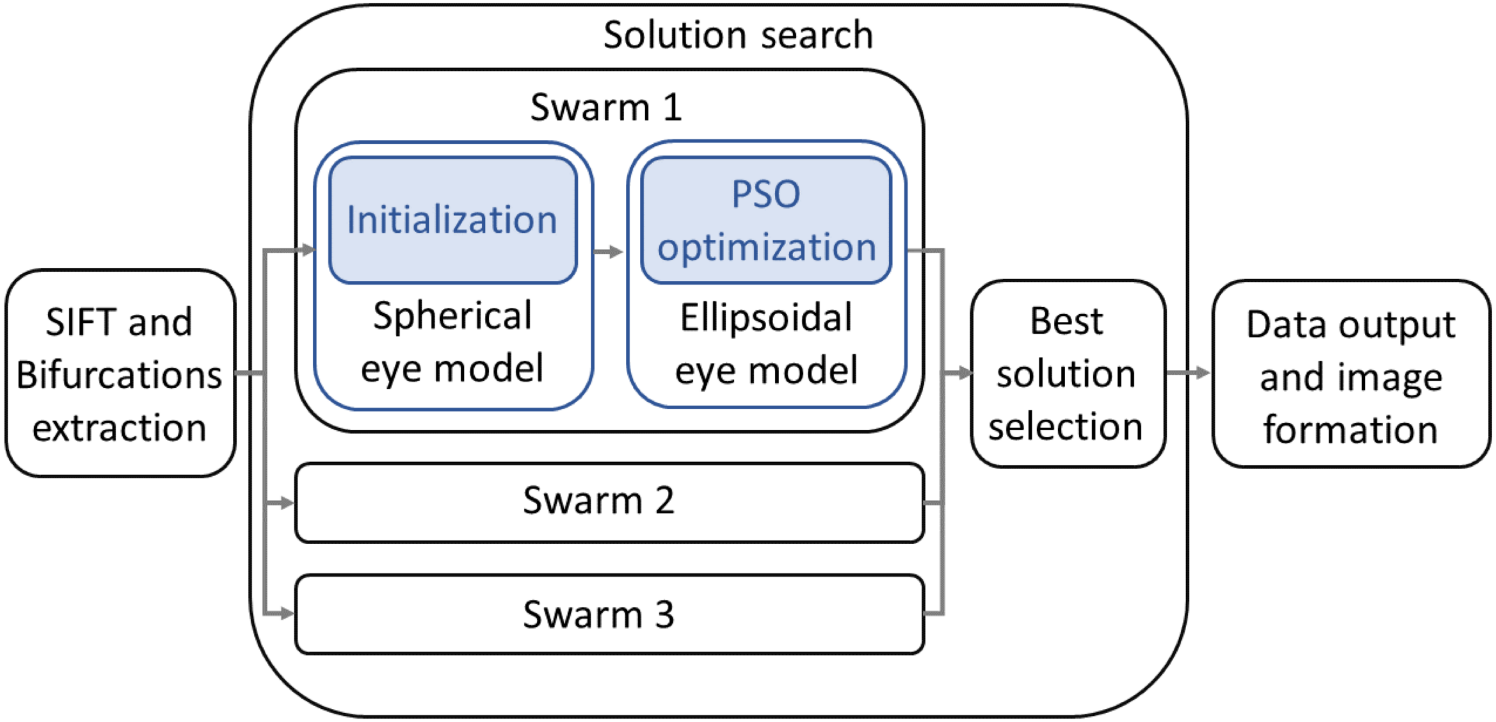
Two eye models are utilized:

- **Sphere** [Navarro 1985]: Simplest full eye approximation.
  - A = $[a, b, c] = [12, 12, 12]$
  - Q = $[r_a, r_b, r_c] = [0, 0, 0]$
  - Only {R, t} are calculated (6 parameters)
- **Ellipsoid**: The most complex model used.
  - A = $[a, b, c] = [\rho_a, \rho_b, \rho_c]$
  - Q = $[r_a, r_b, r_c] = [\theta_a, \theta_b, \theta_c]$
  - {R, t, A, Q} are calculated (12 parameters)





Swarm structure



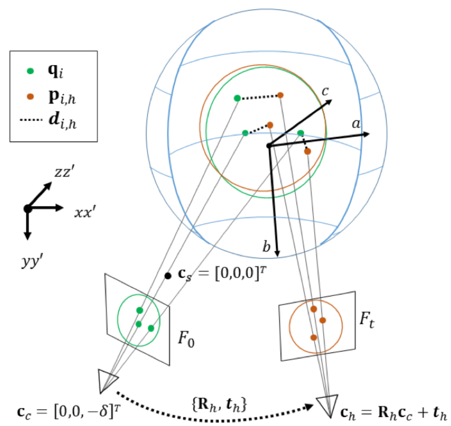
Swarm structure

Initialization:

- **Random Sample Consensus (RANSAC)** [Fischler 1981]: Estimates the 3D pose of an object given **a set of 2D-3D correspondences** and the camera projection matrix. Spherical eye model

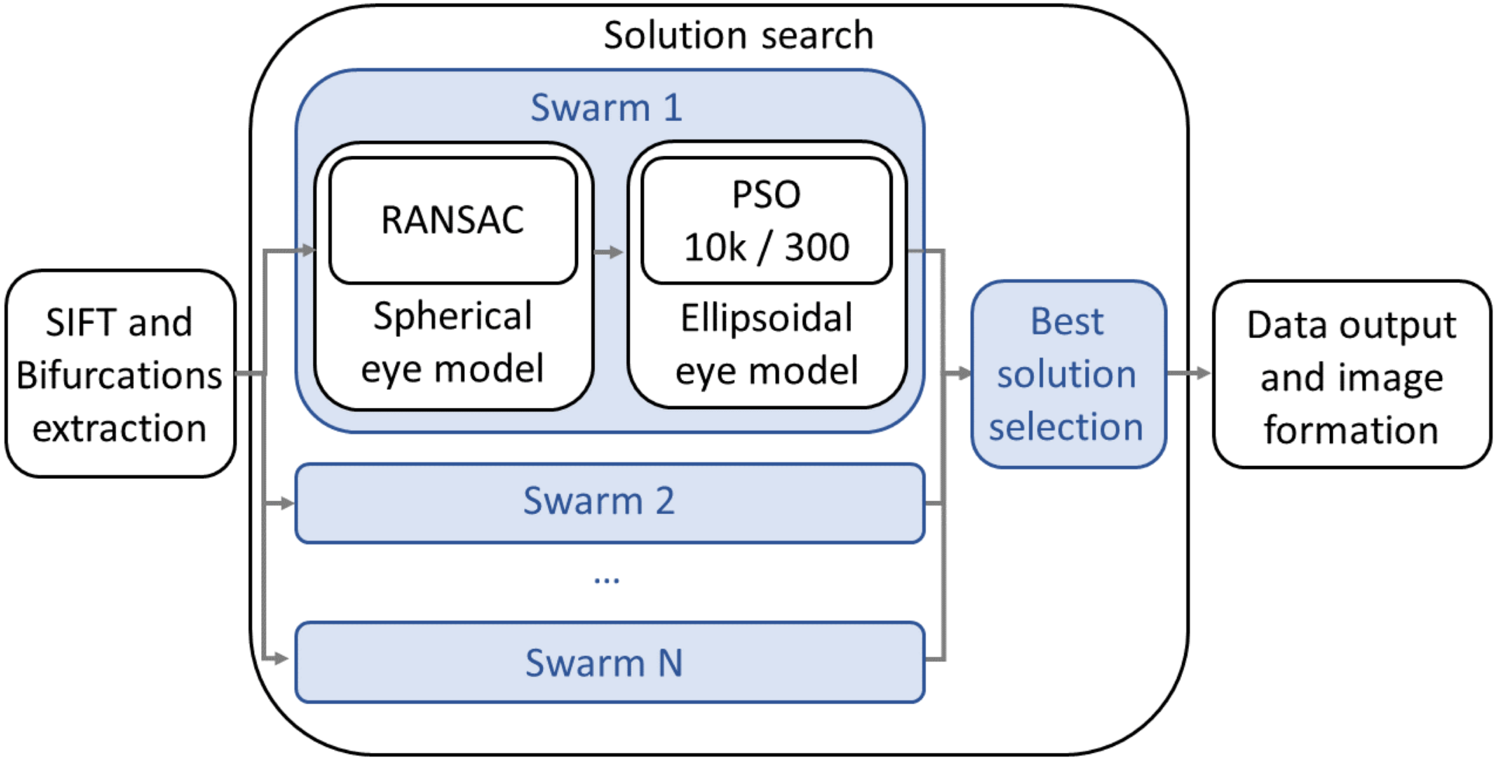
Optimization

- Attempt to **minimize objective function**. Sum of the 80% shortest distances of the corresponding points on the eye model
- We look for the solution on a search space with 12 dimensions. 1 for each solution parameter.
- **Particle Swarm Optimization (PSO)** [Kennedy 1995]:
  - Particles are given random initial position and velocity in the space.
  - Each particle represents a candidate solution (objective function evaluation)
  - Particles evolve through generations.
  - Requires few configuration parameters and no derivatives

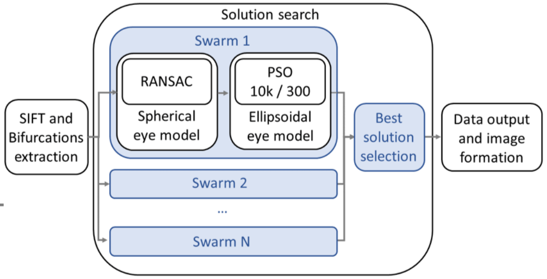


$$o(S_h) = \sum_j |q_j - p_{j,h}|$$

Multiple swarms



Multiple swarms



Both **RANSAC** and **PSO non-deterministic**

The solution search is executed **multiple parallel** times, denoted as **swarms**

The parameters of the **best overall** score in the objective function are **selected** as the solution.

This leads to an **increase** on the computational **cost**, but this solution offers **increased accuracy**, **robustness** and **reliability**.

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Retinal image datasets

Plenty of retinal image **datasets** for **diverse purposes**

- **Segmentation**: CHASEDB1, DRIONS-DB, Drishti-GS, DRIVE, HRF, MESSIDOR, ONHSD and REVIEW
- **Diagnosis**: DIARETDB0, DIARETDB1, e-ophtha, INSPIRE-AVR, ROC, STARE and VICAVR
- **User authentication**: VARIA
- **Retinal image registration**: RODREP

Hard to find datasets suitable for retinal image registration:

- Most datasets have **no image pairs for the same eye**
- **No** datasets with **ground truth** to evaluate registration

	Images	FOV	Resolution	Pairs	Large overlap	Small overlap	Anatomical differences	Ground truth
e-ophtha	463	45^o	2544x1696	144	Yes	Yes	No	No
RODREP	1120	45^o	2000x1312	1400	Yes	Yes	No	No
VARIA	233	20^o	768x584	154	Yes	No	No	No

FIRE dataset

Fundus Image Registration Dataset:

- **129 real** retinal images acquired with a fundus camera
- **134** image **pairs**
- **3 categories**
- Some image pairs with **anatomical differences**
- **Evaluation** via manually annotated **control points**

	Images	FOV	Resolution	Pairs	Large overlap	Small overlap	Anatomical differences	Ground truth
e-ophtha	463	45^o	2544x1696	144	Yes	Yes	No	No
RODREP	1120	45^o	2000x1312	1400	Yes	Yes	No	No
VARIA	233	20^o	768x584	154	Yes	No	No	No
FIRE	129	45^o	2912x2912	134	Yes	Yes	Yes	Yes

S category

S is for "**Similar**"

71 image pairs

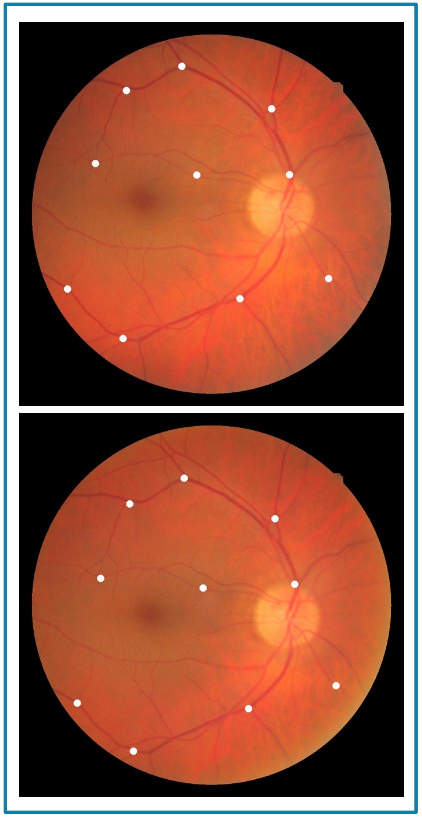
Significant overlap

No anatomic changes

A lot of potential information to use for registration

Least challenging category for registration

Image pairs can be used for super resolution



P category

P is for "**Pose difference**"

49 image pairs

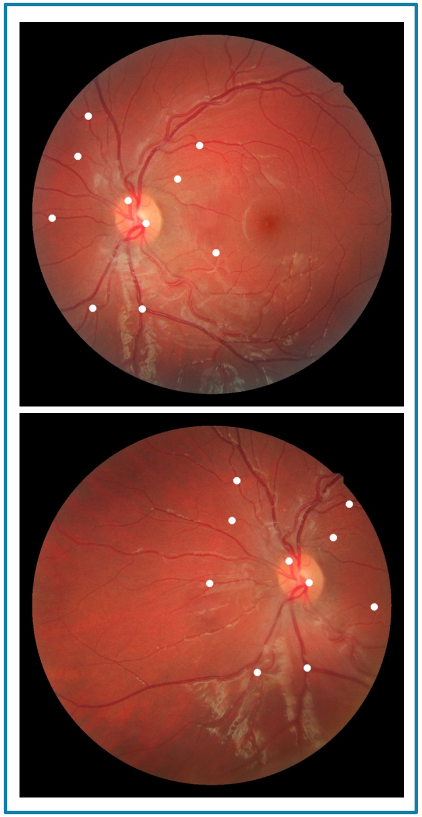
Minor overlap

No anatomic changes

Little potential information to use for registration

More challenging than previous category

Image pairs can be used for creating mosaics of the retina



A category

A is for "**Anatomic difference**"

14 image pairs

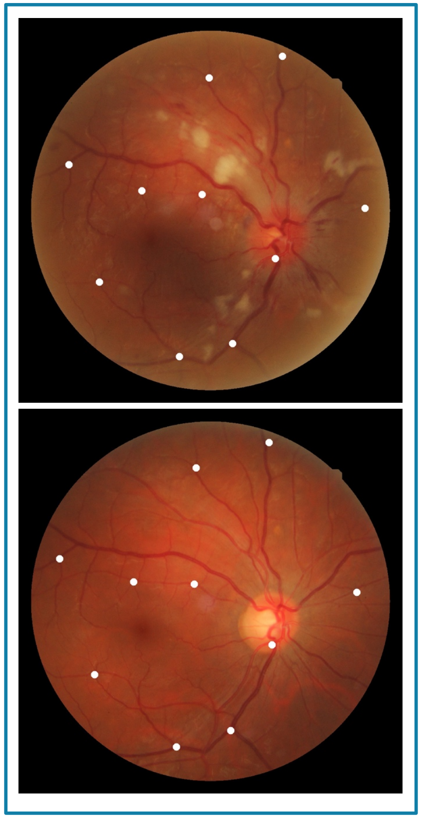
Significant overlap

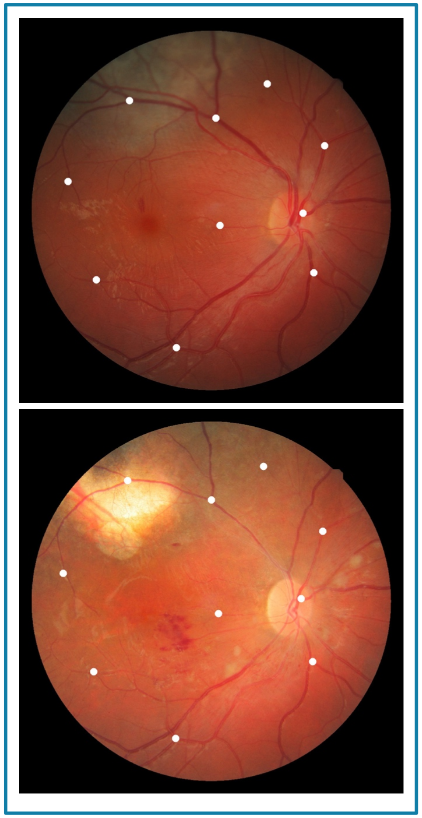
Anatomic changes

Corresponding points may look different due to retinopathy

More challenging than S category

Image pairs can be used for longitudinal studies





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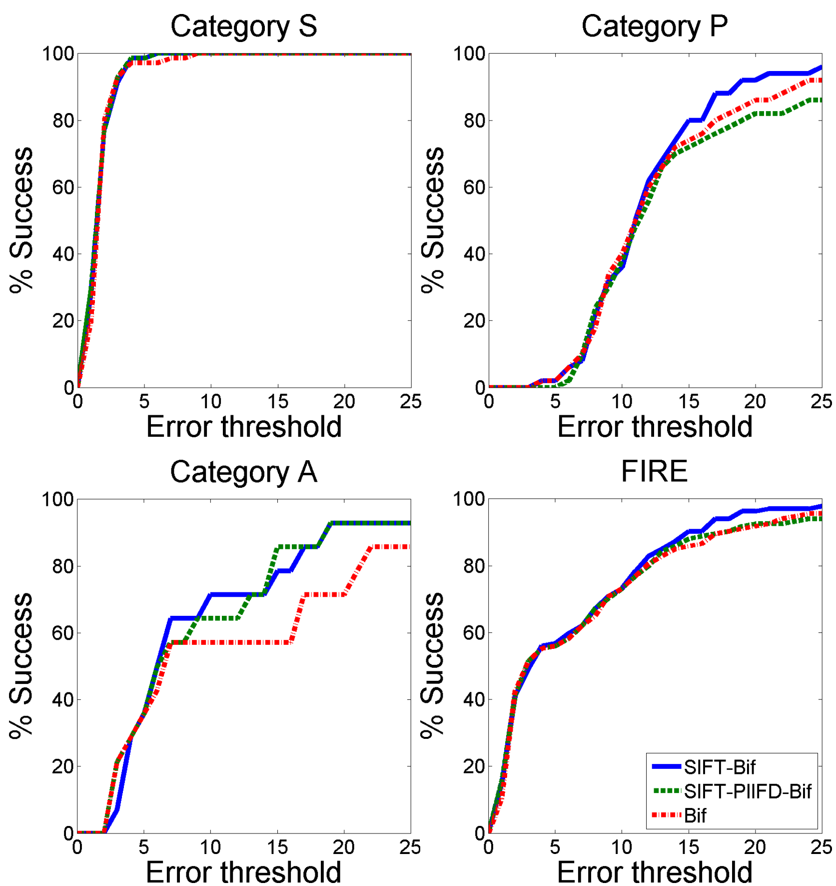
Keypoint evaluation



SIFT	SURF	PIIFD	Bif	S	P	A	FIRE
X				0.945	0.443	0.577	0.721
	X			0.947	0.348	0.466	0.675
		X		0.846	0.134	0.429	0.538
			X	0.953	0.516	0.563	0.751
X	X			0.953	0.423	0.526	0.712
X		X		0.951	0.396	0.503	0.699
X			**X**	0.958	**0.541**	**0.660**	**0.773**
	X	X		0.940	0.264	0.426	0.636
	X		X	0.956	0.404	0.489	0.703
		X	X	0.954	0.472	0.563	0.736
X	X	X		0.952	0.333	0.491	0.674
X	X		X	0.956	0.435	0.480	0.713
X		X	X	**0.959**	0.490	0.657	0.754
	X	X	X	0.954	0.400	0.474	0.699
X	X	X	X	0.956	0.409	0.514	0.707

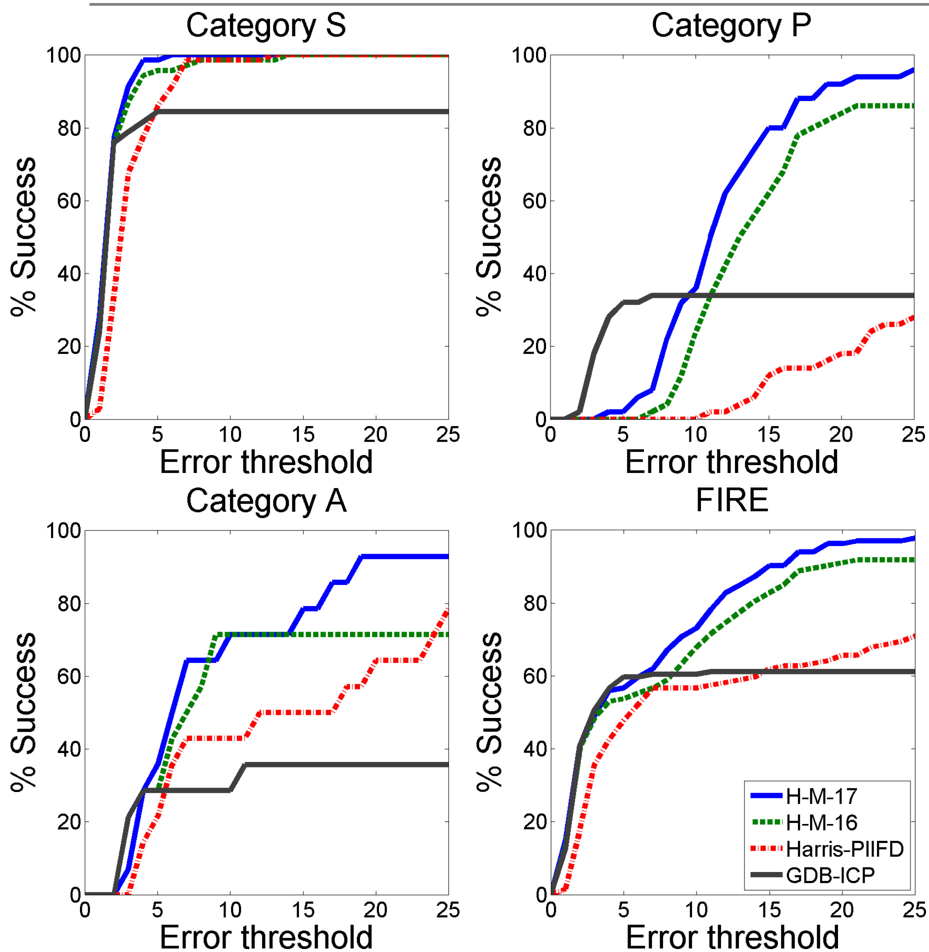
Competing methods

Method is compared to the previous iteration of the current framework [Hernandez-Matas 2016], as well as GDB-ICP and Harris-PIIFD, which are widely applied in the field.

Generalized Dual-Bootstrap Iterative Closest Point (GDB-ICP) [Yang 2007]: a local registration method in the spatial domain that performs quadratic registration of intra- and cross-modal retinal images. Face and corner points are used to iteratively register the image pair.

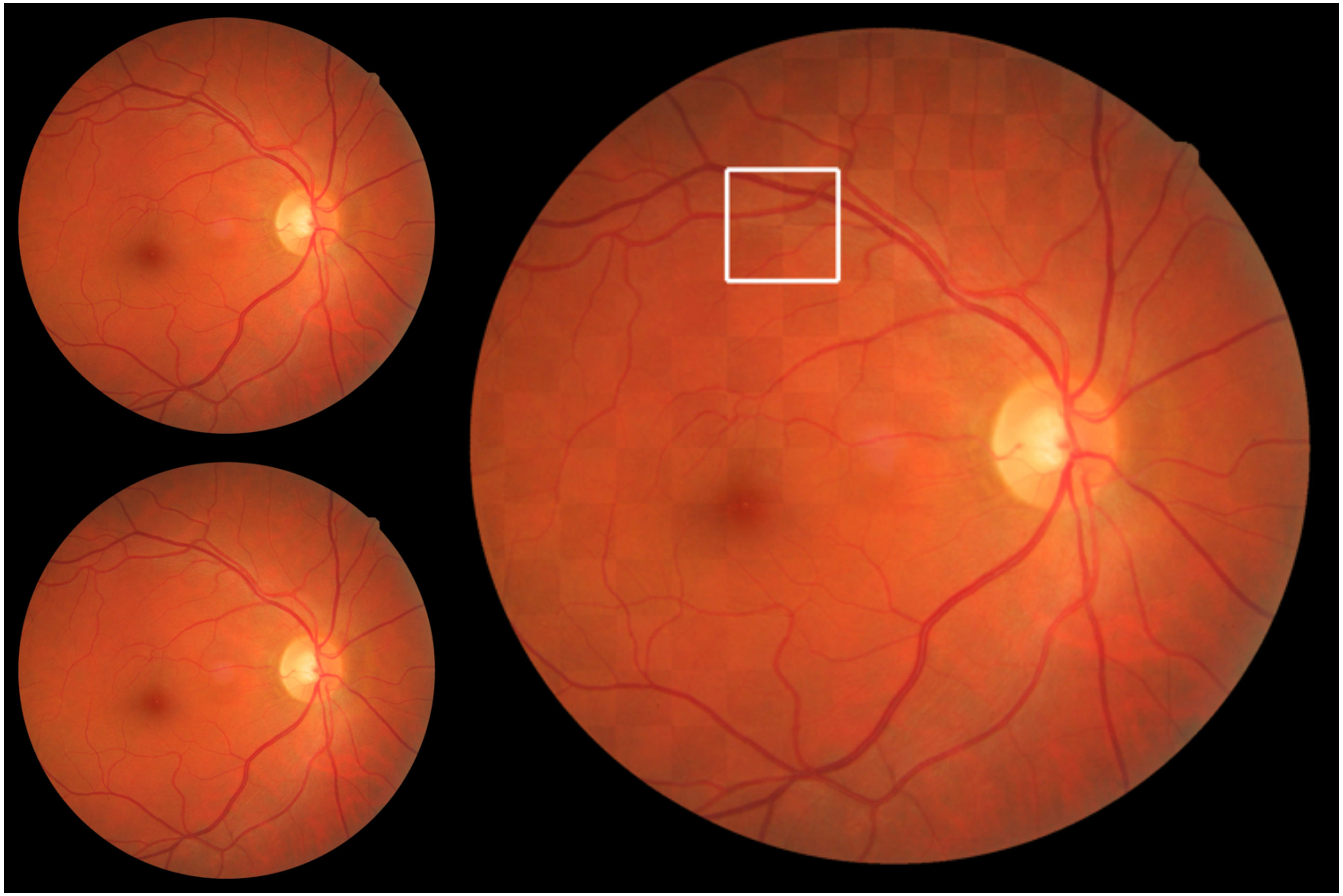
Harris-PIIFD [Chen 2010]: a local registration method in the spatial domain that performs quadratic registration of intra- and cross-modal retinal images. Corner points are selected and PIIFD are extracted. An adaptive transformation is used to register the image pairs.

Competing methods

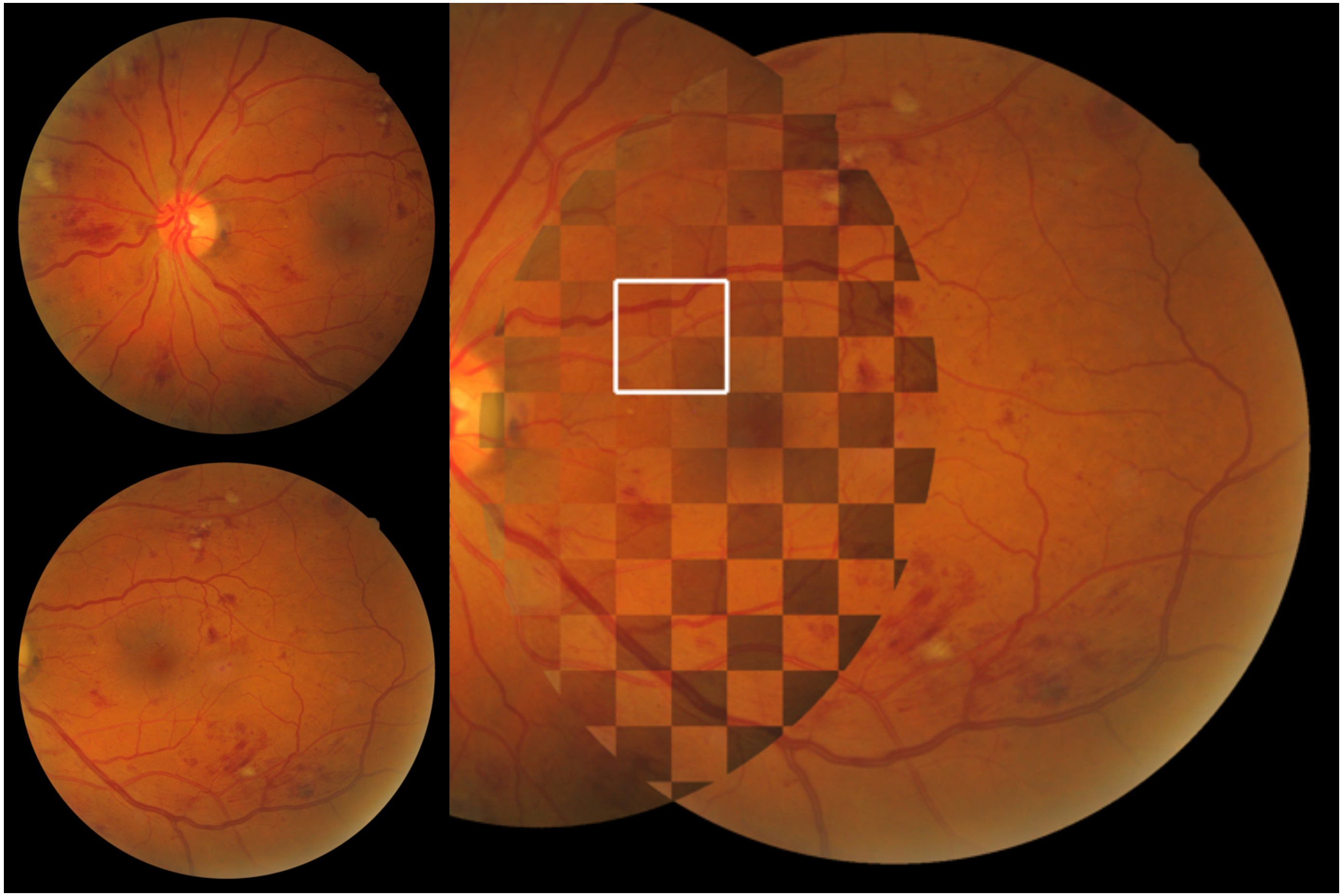


Method	S	P	A	FIRE
H-M'17	**0.958**	**0.541**	**0.660**	**0.773**
H-M'16	0.945	0.443	0.577	0.721
Harris-PIIFD	0.900	0.090	0.443	0.553
GDB-ICP	0.814	0.303	0.303	0.576

Registration results S



Registration results P



Registration results A

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REMPE Registration executable

http://www.ics.forth.gr/cvrl/rempe

FIRE dataset

http://www.ics.forth.gr/cvrl/fire

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Thank you for your attention!