Non-Rigid Registration to Capture Optic Nerve Head Variability

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Background and Purpose

Glaucoma is one of the most common reasons for avoidable blindness. During the progression of the disease, the appearance of the optic nerve head (ONH) changes. Most glaucoma indices rely on geometric measurements and thus utilize only sparse information.

We describe the variations of the ONH by exploiting information from the whole image captured in dense deformation fields. These are generated with an **inter-subject registration technique**.

Key Ideas

We propose a two stage registration approach:

1. Elimination of translation variations by a rigid registration.
2. Description of the ONH shape variability by a non-rigid registration.

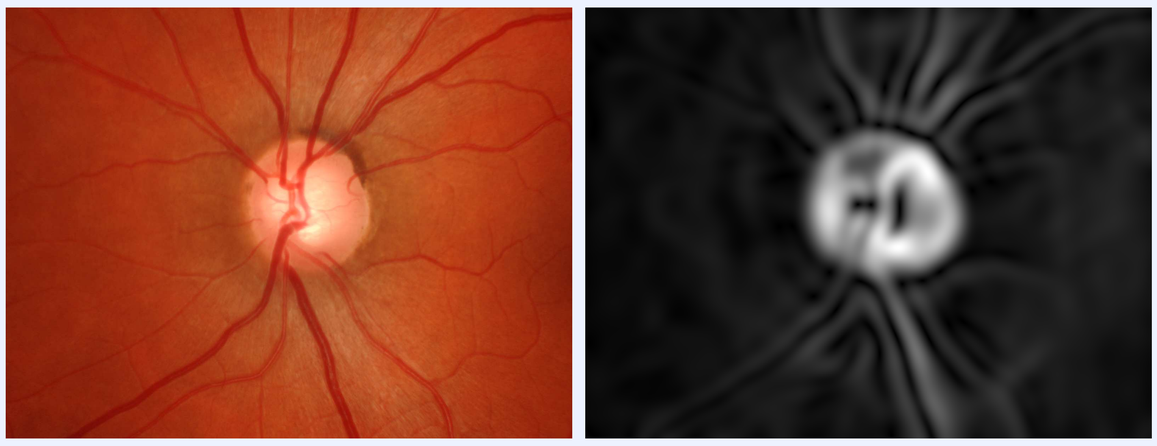
Method: Elimination of translation variations

Variations caused by the acquisition are eliminated:

→ Preprocessing by **Gaussian smoothing and a gradient filter**: (Fig. 1):

- ONH is enhanced as region of interest.
- Individual vessel structures are suppressed.
- Sensitivity to luminosity inhomogeneities is decreased.

→ **Intensity based rigid registration**



(a) (b)

Figure 1: Preprocessing for rigid registration: The gradient magnitude image (b) computed from the input image (a) emphasizes the ONH as region of interest.

Method: Capturing of ONH shape variability

The ONH shape variability is described with dense deformation fields:

→ **Intensity based non-rigid registration**. Goals:

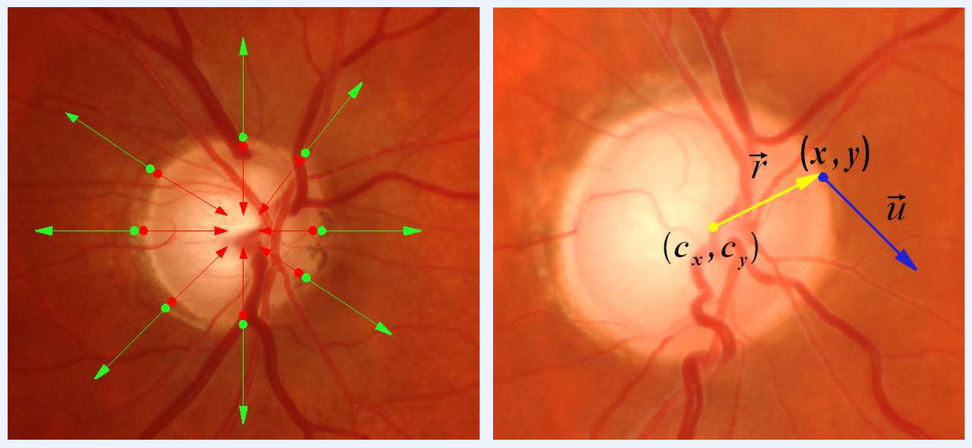
- **Shape adaption:** The ONH shapes have to be deformed for similarity.
- **Avoidance of unnatural shapes:** The circularity of the ONH has to be preserved.

→ Solution: **Radial smoothing** for circular growing and shrinking (Fig. 2)

→ Deformation directions $\boldsymbol{u}$ are evaluated.

→ Deviations from radial directions $\boldsymbol{r}$ are penalized.

$$S_{RS}(\boldsymbol{U}) = \sum_{i,j} \left(\|\boldsymbol{u}(i,j)\|_\epsilon^2 - \left(\frac{\boldsymbol{u}^{\mathrm{T}}(i,j)\boldsymbol{r}(i,j)}{\|\boldsymbol{r}\|_\epsilon} \right)^2 \right)$$



(a) (b)

Figure 2: Radial smoothing: Requested circular growing and shrinking (a), deformation direction $\boldsymbol{u}$ differs from radial direction $\boldsymbol{r}$ (exiting from center (c_x, c_y)) at position (x, y) (b)

Results

Data set for evaluation:

- Image size of 1600×1212 acquired with a Kowa non-myd camera
- 60 randomly chosen image pairs
- Gold standard: Automatically determined translation between ONH centers and segmented OHN rims

Rigid registration:

- Metric used in the registration: Normalized correlation
- Sufficient translation distance: $<$ 150 pixels
- Before registration 53.33% of image pairs had a sufficient translation distance
- After registration 78.3% had a sufficient translation distance

→ Reasonable compensation of translation variations

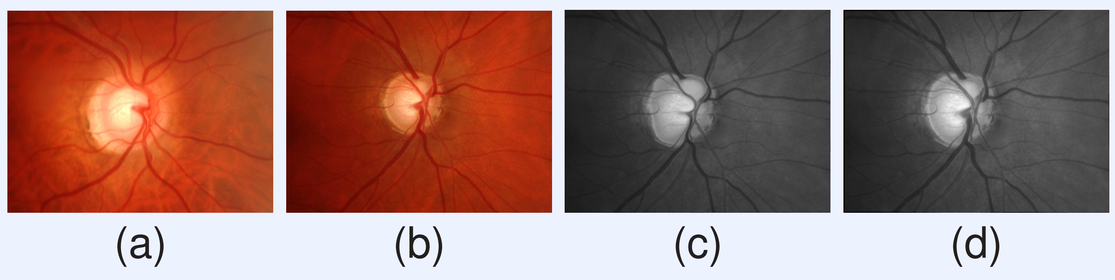
Non-rigid registration:

- Metrics used in the registration: Sum of squared distances (SSD), mutual information (MI)
- Combinations with and without radial smoothing (RS)
- Radius differences before and after registration

Metric	Average error	Standard deviation
Initial	45.08	39.46
MI	41.95	38.97
MI + RS	43.60	40.69
SSD	34.52	38.00
SSD + RS	34.52	33.14

→ SSD with RS shows most reliable results

→ Only RS ensures naturally circular deformations (Fig. 3)



(a) (b) (c) (d)

Figure 3: Reference (a), template (b) and result of non-rigid registration using **sum of square differences stand-alone** (c) and in combination with **radial smoothing** (d) showing that the radial smoothing is able to preserve the natural circular optic nerve head appearance.

Conclusion

An automatic registration technique was developed to describe successfully the ONH shape variations by dense deformation fields preserving its natural shape.

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