Automatic Delineation of Macular Regions Based on a Locally Defined Contrast Function

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SPECTRUM LAB

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Macular Regions

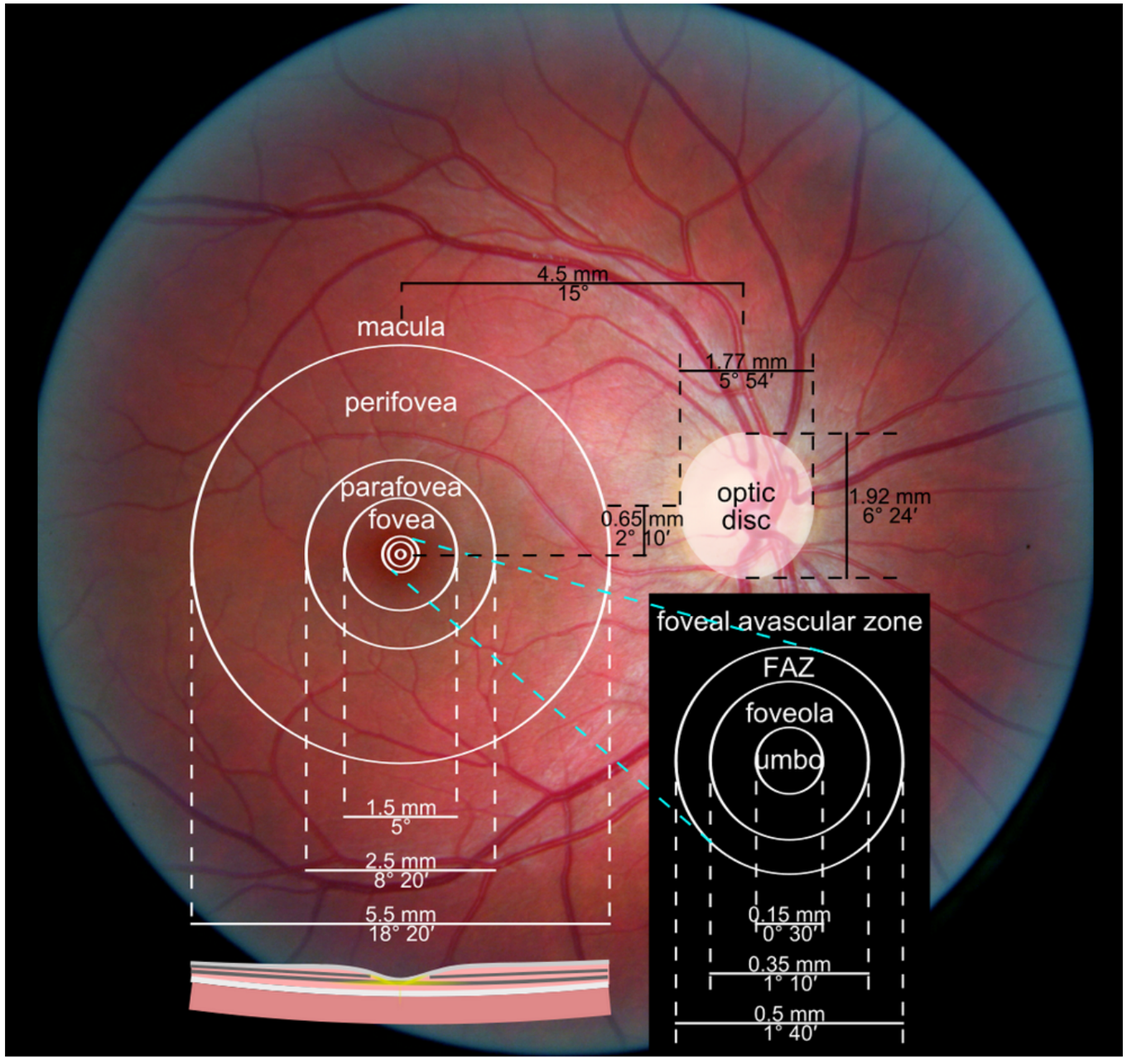

Figure: Retina with overlay diagrams showing the positions and sizes of the macula, fovea, and optic disc

Image courtesy: https://en.wikipedia.org/wiki/Macula_of_retina#/media/File:Macula.svg

Macular Pathologies

- Macular degeneration: Progressive destruction of the macula
- Macular hole: Burst of blood vessels going to the macula
- Diabetic macular edema: Accumulation of fluid in the macula
- One of the leading causes of blindness
  (Global data on visual impairments: World Health Organization)
- Fundus imaging: inexpensive and noninvasive screening
- Detection, segmentation, quantification: Important steps for severity assessment

Prior Art

- Punnolil (*ICACCI, 2013*) – depends on optic disc diameter
- Media et al. (*IEEE INDICON, 2014*) – depends on optic disc diameter

  (The above two methods divide the macula into three regions)
- Lim et al. (*IEEE CHSE, 2011*) – depends on optic disc diameter

  (The above method divide the macula into two regions)
- Lu et al. (*ICIP, 2010*) – depends on the circular brightness profile of macula
- Niemeijer et al. (*IEEE TMI, 2007*) – fovea center detection and estimation

Contents

Highlights

- Active-disc-based segmentation
- Automated initialization using matched filtering
- Computationally efficient algorithm
- Fovea segmentation and macular region delineation
- Java and iOS implementation
- Validation on various fundus image databases

Active Disc Design

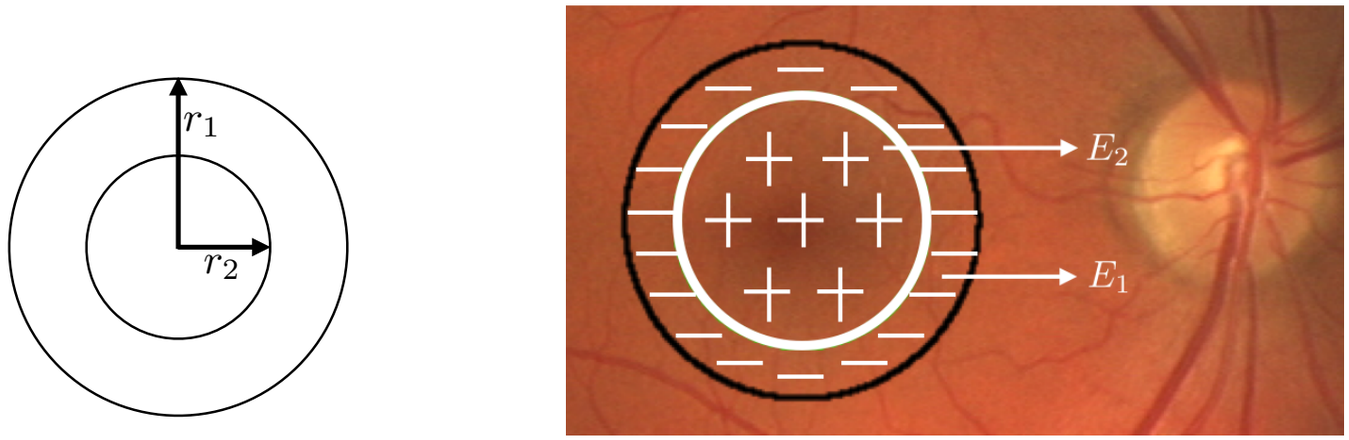

Figure: Circular active disc template and its convergence on the fovea

- Use circular template
- Design motivated by circle and ellipse fitting algorithms (Thevenaz et al., *IEEE TIP 2008, PAMI 2011*)
- A unified formulation for circle and ellipse fitting without the explicit regularization (Pediredla and Seelamantula, *ICASSP, 2012*)
- Recent applications in ophthalmology *(GlobalSIP, 2015)*

Template Parametrization

- Equations for circular template:

$$x_i(t) = r_i \cos t \ ; \ \ y_i(t) = r_i \sin t \ ; \ \text{for } i = 1, 2, \text{and } \forall t \in (0, 2\pi]$$

$$r_1 = 1; \ \ r_2 = 1/\sqrt{2}$$

- Restricted affine transform:

$$X_i = Rx_i + x_c, \ \ Y_i = Ry_i + y_c$$

- Disc energy:

$$E = \frac{1}{R^2}(E_1 - 2E_2)$$

where $E_i = \iint_{\mathcal{R}_i} f(X, Y)\, \mathrm{d}X\, \mathrm{d}Y, \qquad i = 1, 2.$

Optimization

- Gradient ascent with adaptive step size
- Region integrals to contour integrals using Green's theorem for efficient computation of partial derivatives

$$\frac{\partial E}{\partial R} = \frac{1}{R}\left(\int_{t=0}^{2\pi} f(X_1, Y_1)\,\mathrm{d}t - \int_{t=0}^{2\pi} f(X_2, Y_2)\,\mathrm{d}t - 2E \right),$$

$$\frac{\partial E}{\partial x_c} = \frac{1}{R^2}\left(\int_{t=0}^{2\pi} (\sqrt{2} f(X_1, Y_1)\,\mathrm{d}t - 2f(X_2, Y_2)) \cos t\,\mathrm{d}t \right),$$

$$\frac{\partial E}{\partial y_c} = \frac{1}{R^2}\left(\int_{t=0}^{2\pi} (\sqrt{2} f(X_1, Y_1)\,\mathrm{d}t - 2f(X_2, Y_2)) \sin t\,\mathrm{d}t \right).$$

- Maximize to converge on to fovea

Initialization

- Matched filtering with a natural fovea template

$$s(x_p, y_p) = \iint f(x, y)\, m(x - x_p, y - y_p)\, \mathrm{d}x\, \mathrm{d}y$$

- Localizing the fovea and for initializing the active disc
- No optic disc detection/segmentation of blood vessels required

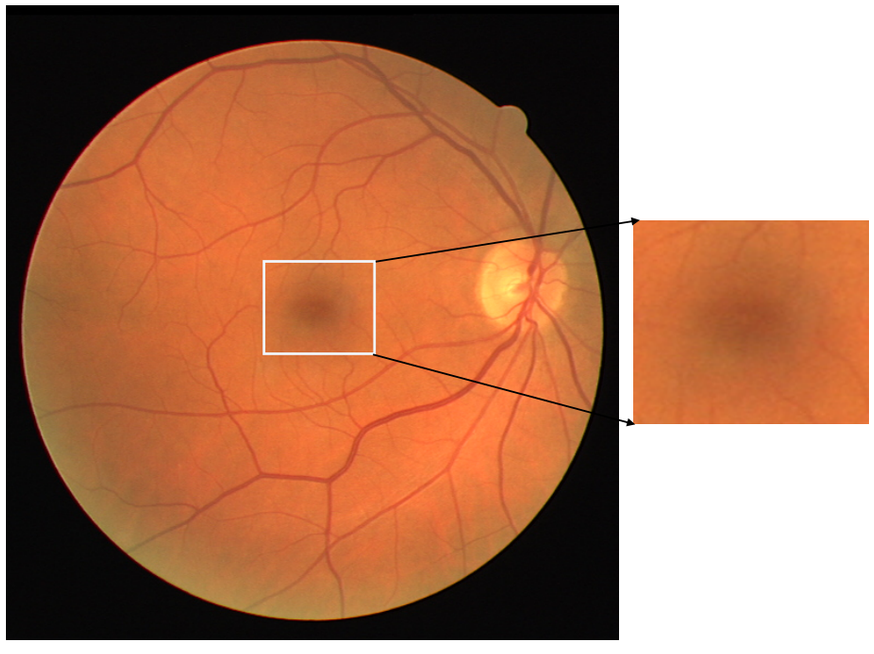

Figure: Natural fovea template cropped from the fundus image

Macular Region Delineation

- Macular regions: FAZ*, fovea, parafovea, perifovea (all annular)
- We follow histological characterization of macula:
  $\mathrm{macula} : \mathrm{parafovea} : \mathrm{fovea} : \mathrm{FAZ} = 5.5 : 2.5 : 1.5 : 0.5$
  (Remington, *Clinical Anatomy and Physiology of the Visual System,* Elsevier, 2012)
- Segmented fovea is the reference for delineating the other regions
- Concentric circles with converged active disc centre and radius

$$(x - x_c)^2 + (y - y_c)^2 = (\alpha R)^2$$

*Foveal Avascular Zone

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Algorithm Versus Expert Outlines

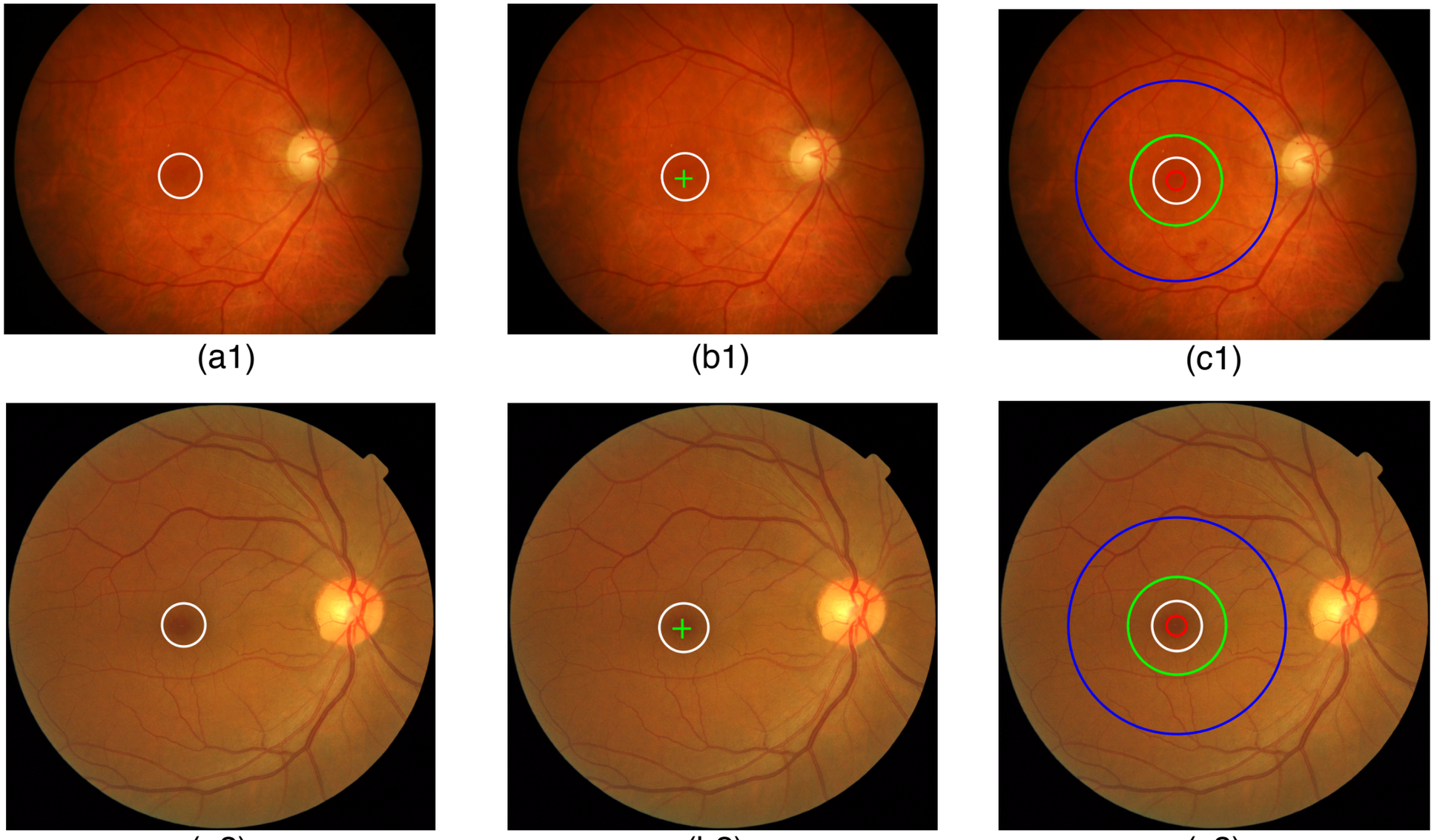

Figure: Macular region outlines on fundus images. (a1)–(a2): fovea marked (in white) by an expert; (b1)– (b2): Fovea localization (green +) and algorithm outline of the fovea (white), and (c1)–(c2): algorithm based macular region delineation (FAZ – red, fovea – white, parafovea – green, perifovea – blue)

Quantitative Comparison

Database	Number of fundus images	Average Dice index
DRIVE	40	77.78%
DIARETDB0	130	67.46%
MESSIDOR	200	76.56%

Performance Comparison of Various Fovea Localization Techniques

Database	Database (Number of fundus images)	Detection accuracy
Synthanayothin et al.	Local (112)	80.40%
Niemeijer et al.	Local (600)	94.40%
Marino et al.	Local (135)	93.33%
Zhang et al.	Local (139)	98.10%
Media et al.	DRIVE, Aria, and DIARETDB1 (50 images chosen)	100.00%
Proposed method	DRIVE (40) DIARETDB0 (130) MESSIDOR (1200)	100.00% 92.00% 99.40%

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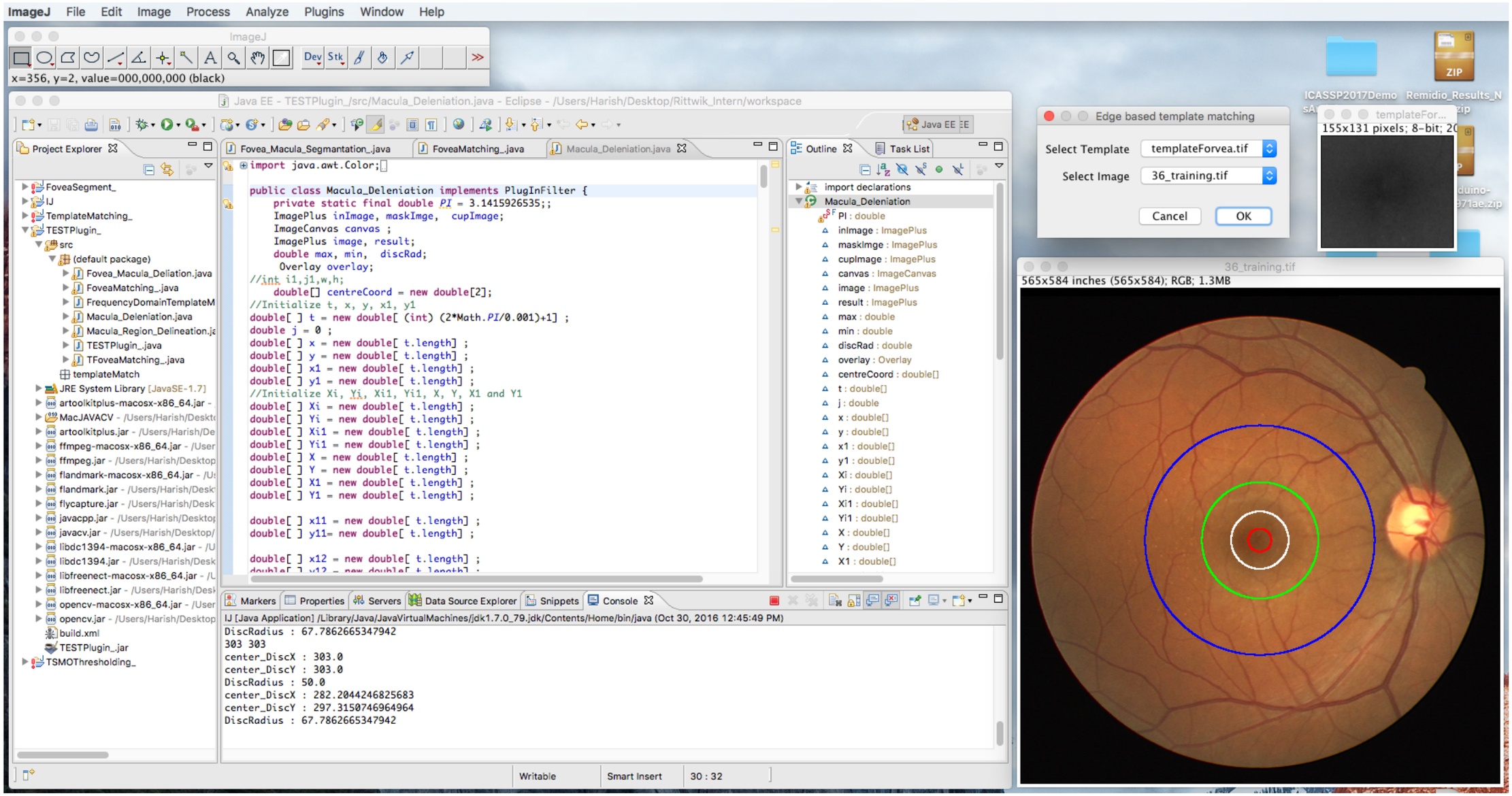
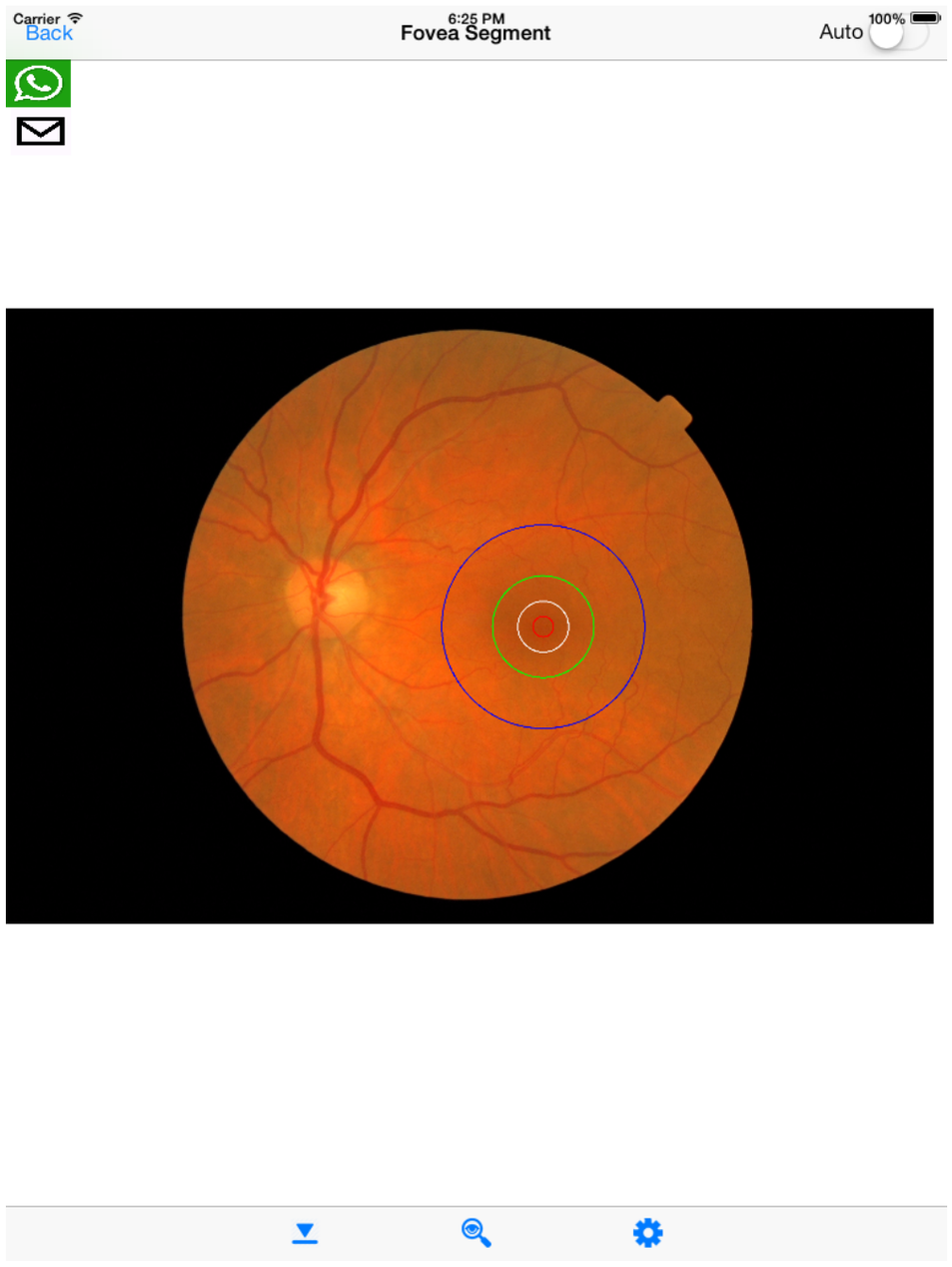
Software

- ImageJ (NIH) plugin



Software

- iOS implementation



Demo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Demo


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Conclusions and Outlook

To summarize:

- Active-disc-based segmentation of fovea and macular region delineation
- Formulation relatively simple, yet effective
- Good fovea detection and reasonable segmentation accuracy
- ImageJ plugin and iOS implementation available

Future work:

- Severity analysis of maculopathy
- Faster optimization (second-order methods)

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Thank you.