Spline-Based Refinement of Vessel Contours in Fundus Retinal Images for Width Estimation

Alessandro Cavinato [*†] Lucia Ballerini [*] Emanuele Trucco [*] Enrico Grisan [†]

[*]School of Computing, University of Dundee, UK [†]Department of Information Engineering, University of Padova, Italy

Abstract

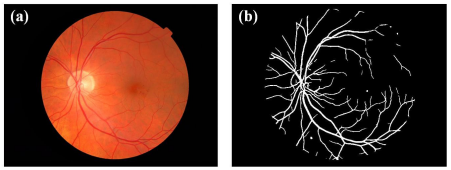
Aim: refine vessel contours obtained from raw retinal binary maps to improve the accuracy of vessel width estimation

- Preprocessing
- Vessel centreline computation and refinement
- Vessel edge extraction
- Contour refinement using coupled splines
- Width estimation

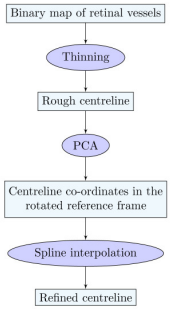
Results show width estimate performance comparable with state-of-the-art methods

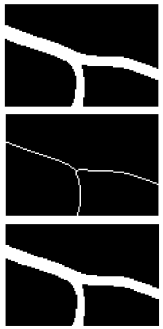
Preprocessing

The vessel segmentation algorithm convolves the image with a Gaussian sliding window in order to enhance the contrast between vessel and non-vessel pixels, then applies a threshold to the response image. This generates the binary vessel maps which are regularized by the proposed method

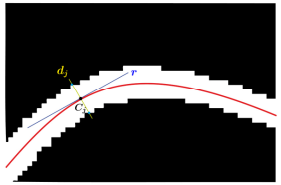


Vessel centreline computation and refinement





Vessel edge extraction



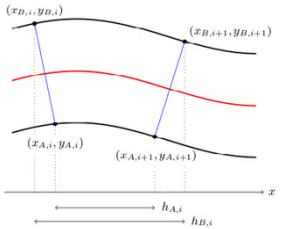
Two lists Q_A and Q_B of coupled vessel edge points

subsampling

Two lists L_A and L_B

$$L_A = \begin{pmatrix} (x_{A,0}, y_{A,0}) \\ (x_{A,1}, y_{A,1}) \\ \vdots \\ (x_{A,n}, y_{A,n}) \end{pmatrix} \text{ and } L_B = \begin{pmatrix} (x_{B,0}, y_{B,0}) \\ (x_{B,1}, y_{B,1}) \\ \vdots \\ (x_{B,n}, y_{B,n}) \end{pmatrix}$$

Contour refinement using coupled splines



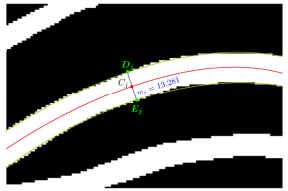
Assuming locally parallel vessel boundaries, a constraint between two parallel splines is enforced at each knot

$$\begin{cases} y_A = a_i(x - x_{A,i})^3 + b_i(x - x_{A,i})^2 + c_i(x - x_{A,i}) + d_i \\ y_B = \alpha_i(x - x_{B,i})^3 + \beta_i(x - x_{B,i})^2 + \gamma_i(x - x_{B,i}) + \delta_i \\ y'_A(x_{A,i+1}) = y'_B(x_{B,i+1}) \end{cases}$$

This system is overconstrained by the parallelism constraint at knots, and is solved by least squares

Width estimation

The vessel width at C_j is estimated as the Euclidean distance w_j between D_j and E_j



Results

The width measurement performance is evaluated using the publicly available REVIEW database: *http://ReviewDB.lincoln.ac.uk*

Difference: $\chi_i = w_i - \psi_i$ difference mean: μ_χ difference standard deviation: σ_χ

Method	Measurement		Difference		SR %	Measurement		Difference		SR %
	μ	σ	μ_χ	σ_χ		μ	σ	μ_χ	σ_χ	
	HRIS					CLRIS				
First observer: O_1	4.12	1.25	-0.23	0.288	100	13.19	4.01	-0.61	0.567	100
Second observer: O_2	4.35	1.35	0.002	0.256	100	13.69	4.22	-0.11	0.698	100
Third observer: O_3	4.58	1.26	0.23	0.285	100	14.52	4.26	0.72	0.566	100
Ground truth: O	4.35	1.26	-	-	100	13.80	4.12	-	-	100
ESP [6]	4.63	-	0.28	0.420	99.7	15.7	-	-1.90	1.469	93.0
Graph [7]	4.56	1.30	0.21	0.567	100	14.05	4.47	0.08	1.78	94.1
Proposed method	**3.93**	**1.40**	**-0.42**	**0.760**	**95.7**	**13.81**	**3.68**	**-0.16**	**1.229**	**90.2**
	VDIS					KPIS				
First observer: O_1	8.50	2.54	-0.35	0.543	100	7.97	0.47	0.45	0.233	100
Second observer: O_2	8.91	2.69	0.06	0.621	100	7.60	0.42	0.08	0.213	100
Third observer: O_3	9.15	2.67	0.30	0.669	100	7.00	0.52	-0.53	0.234	100
Ground truth: O	8.85	2.57	-	-	100	7.52	0.42	-	-	100
ESP [6]	8.80	-	-0.05	0.766	99.6	6.56	-	-0.96	0.328	100
Graph [7]	8.35	3.00	-0.53	1.43	96.0	6.38	0.59	-1.14	0.67	99.4
Proposed method	**8.17**	**2.82**	**-0.79**	**1.381**	**92.1**	**6.06**	**0.28**	**-1.32**	**0.319**	**93.9**

Want to find out more? Scan with your camera phone:
VAMPIRE website - University of Dundee