SEGMENTATION OF RETINAL ARTERIAL BIFURCATIONS IN 2D ADAPTIVE OPTICS OPHTHALMOSCOPY IMAGES

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Context - Goals

RHU TRT cSVD (ANR-16-RHUS-0004) **:** to study CADASIL syndrome, a disease affecting cerebral small vessels and responsible for strokes and cognitive decline.

PARADIGM: Retinal vessels are related to cerebral vessels, sharing many structural, functional and pathological features.

ADAPTIVE OPTICS OPHTALMOSCOPY: high resolution imaging modality (~$1\mu m$/pix) allowing to visualize microstructures in the retina (www.imagine-eyes.com).

PREVIOUS WORK: arterial wall segmentation of individual branches (AOV) [1].

GOALS: to extend the method to the segmentation of bifurcations in order to estimate accurately the branch diameters at the bifurcation and calculate biomarkers that characterize blood flow. Semi-automatic approach.

1. BIFURCATION SEGMENTATION

METHOD

1. Manual step where the user defines the three vessel branches involved in the bifurcation by placing points on the axial reflections.
2. Automatic segmentation of the 3 branches by AOV [1],
3. Automatic segmentation of the bifurcation and diameter estimation.

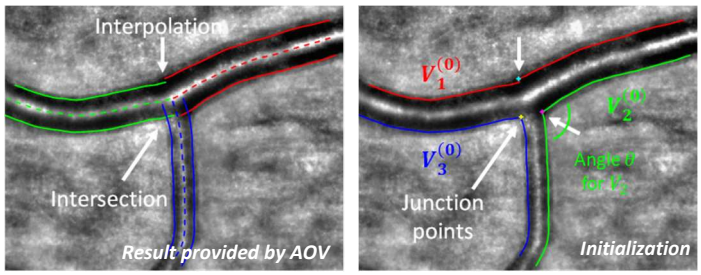


FIGURE 1 – Initialization of the parametric active contour model

ADAPTIVE PARAMETRIC ACTIVE CONTOUR MODEL

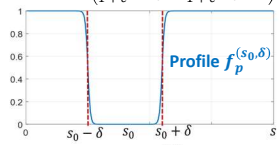
- Lines $V_i^{(0)}, i = 1,2,3$, created from the 3 pairs of curves delineating the lumen.
- **Proposed active contour model**:

$$E(V(s)) = \int_0^1 -|\nabla I(V_i(s))| + \alpha(s)|V_i'(s)|^2 + \varphi(s)\left|V_i(s) - V_i^{(0)}(s)\right|^2 ds$$

Regularization 1 Regularization 2

- **Adaptive weighting** of two regularization terms in order to take into account:
  1. The bifurcation geometry: $\boldsymbol{\alpha(s)}$ low at the junction point s_0 for acute angles θ.
  2. The initial segmentation, reliable outside the bifurcation: $\boldsymbol{\varphi(s)}$ and $\boldsymbol{\alpha(s)}$ high far from the bifurcation.

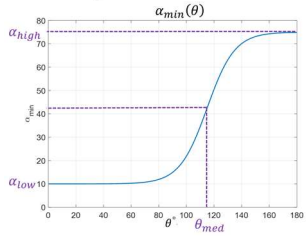
$$f_p^{(s_0,\delta)} = max\left(\frac{1}{1+e^{-(s-s_0-\delta)}}, \frac{1}{1+e^{-(s_0-s-\delta)}}\right)$$

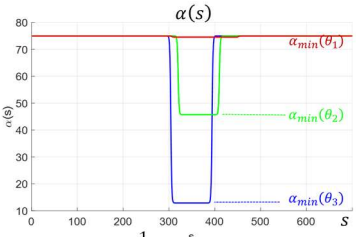


$$\varphi(s) = \varphi_0 f_p^{(s_0,\delta)}(s)$$

$$\alpha(s) = \alpha_{min} + (\alpha_{high} - \alpha_{min}) f_p^{(s_0,\delta)}(s)$$

(δ related to vessel diameters)





$$\alpha_{min}(\theta) = \alpha_{low} + (\alpha_{high} - \alpha_{low}) \frac{1}{1+\exp(-\gamma(\theta - \theta_{med}))}$$

- Parameters $\varphi_0, \alpha_{low}, \alpha_{high}, \theta_{med}, \gamma$, tuned on a subset of 5 images.

2. BIOMARKERS

BIOMARKERS CALCULATED FROM BRANCH DIAMETERS

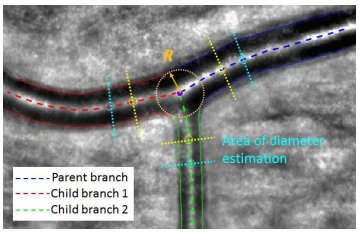


FIGURE 2 – Diameter estimation

Murray's law [2]: $d_0^3 = d_1^3 + d_2^3$

Junction exponent x: $d_0^x = d_1^x + d_2^x$

Branching exponent:

$$\beta_{mes} = \frac{d_1^2 + d_2^2}{d_0^2} = \frac{1+\lambda^2}{(1+\lambda^x)^{\frac{2}{x}}}, \lambda = d_2/d_1$$

Gap to optimal configuration $(x = 3)$:

$$\beta_{dev} = \beta_{optimal} - \beta_{mes}$$

3. EXPERIMENTAL RESULTS

DATABASE AND BIOMARKERS ESTIMATION

images acquired from 23 control subjects, 28 diabetic patients and 25 patients with CADASIL.

Analyzing an artery to the 6th bifurcation ($\varnothing\ 20\mu m - 90\mu m$).

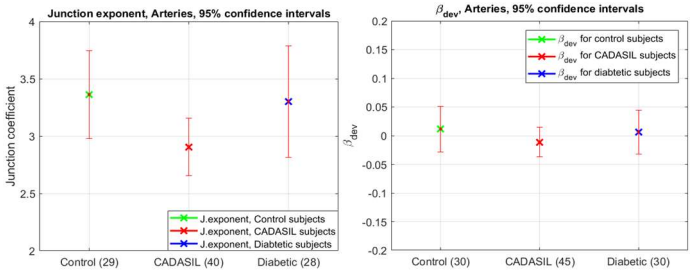


FIGURE 3 – Biomarkers: mean and 95% confidence interval

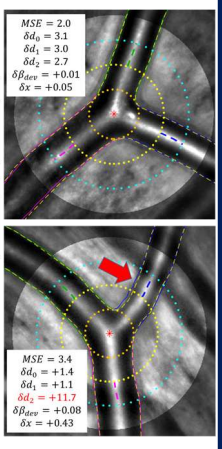
QUANTITATIVE EVALUATION

Manual segmentations of 10 OA images by 3 experts.

- intra/inter-expert(s) and software/expert variability:

	MSE (pixels)	$\delta d_{0,1,2}$ (pixels)	$\delta\beta_{dev}$	δx
Exp_1	2.43 ± 0.90	$+0.84 \pm 2.22$	0.00 ± 0.09	-0.10 ± 0.49
Exp_2	2.80 ± 0.99	-0.62 ± 3.98	0.00 ± 0.11	$+0.41 \pm 1.24$
Exp_3	2.04 ± 0.96	-1.18 ± 2.09	$+0.01 \pm 0.02$	$+0.07 \pm 0.11$

Seg/Ref	MSE	$\delta d_{0,1,2}$	$\delta\beta_{dev}$	δx
Exp_1/Exp_3	2.65 ± 1.48	$+0.06 \pm 4.51$	-0.04 ± 0.07	-0.44 ± 1.20
Exp_2/Exp_3	3.25 ± 1.84	$+0.52 \pm 6.15$	0.00 ± 0.18	-0.40 ± 2.24
$Logiciel/Exp_3$	3.22 ± 1.21	$+2.78 \pm 2.95$	$+0.02 \pm 0.06$	$+0.11 \pm 0.38$



CONCLUSION AND PERSPECTIVES

- **MSE**: similar to the inter-experts variability and slightly higher than the intra-expert variability.
- **Diameters**: consistent with MSE, low over-segmentation.
- **Biomarkers**: similar accuracy or even better than inter/intra expert(s) accuracy.
- **Method**: dynamic weighting of an active contour, to cope with the geometry of every bifurcation and keep the initial segmentation where it is reliable.
- **Limits** : blur in OA images→ segmentation imprecision → inaccuracies in diameter estimates. Sensitivity of biomarkers to diameter imprecision.
- **Perspectives**: processing of the whole vascular tree, neurovascular coupling.

Références

[1] N. Lermé, F. Rossant, I. Bloch, M. Paques, E. Koch, and J. Benesty, A fully automatic method for segmenting retinal artery walls in adaptive optics images. Pattern Recognition Letters, 72 :72–81, 2016.

[2] C. D. Murray. The physiological principle of minimum work : I. The vascular system and the cost of blood volume. Proceedings of the National Academy of Sciences, 12(3) :207–214, 1926.

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