A Supervised Approach for Classifying Corneal Nerves Images in 4 Tortuosity Levels

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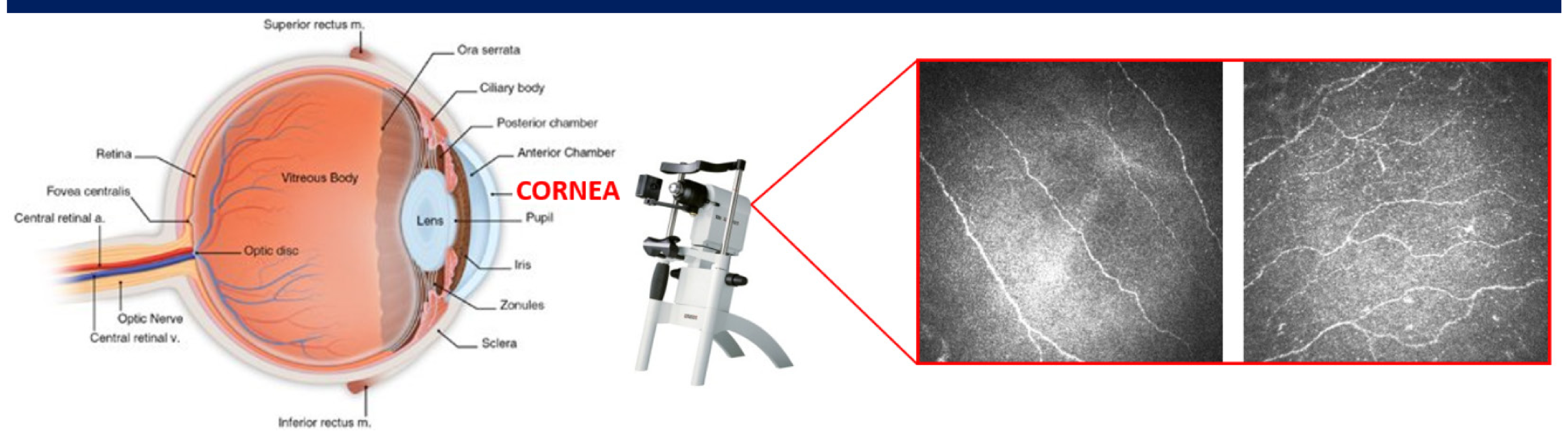
Abstract

We present a novel method for classifying corneal nerves images in 4 levels of tortuosity. We use multi-scale features and a new multi-window algorithm for curvature estimation. A wrapper using logistic ordinal regression or an embedded method based on random forests is applied for feature and scale selection. Tested with 90 images classified by 3 clinicians, the accuracy of our system is 88.89%, 76.67%, 77.22% against each observer, outperforming the best one hold out (76.67%, 76.67%, 75%, respectively).

Clinical Motivation



- Corneal fibres appear QUALITATIVELY more tortuous in some diseases (e.g. keratoconic corneas [1,2], dry eyes [3]);
- Tortuosity significantly higher in Diabetic Retinopathy (DR), one of the leading pathological causes of blindness among working-age people in developed countries [4].

Technical Motivation

MAIN ISSUE: QUALITATIVE assessment leads to high inter-observer and intra-observer variability.

GOAL: to obtain an objective and reproducible tortuosity evaluation.

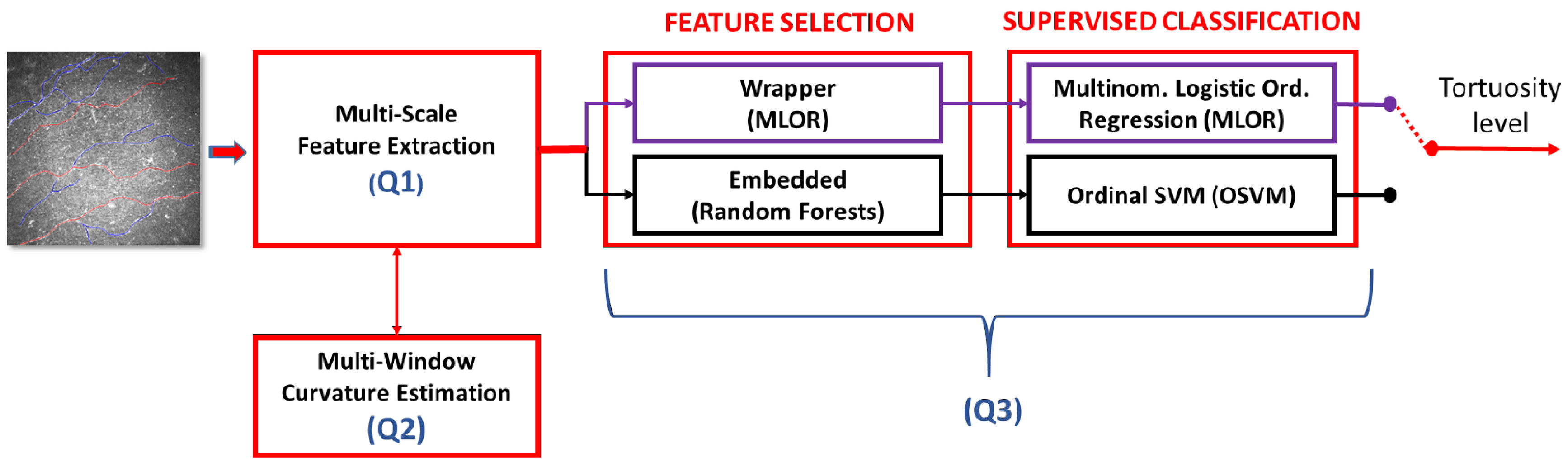
Q1. Does scale play a role?

Q2. Curvature seems a good feature: how accurately can it be estimated?

Q3. Previous work: is this the right approach?

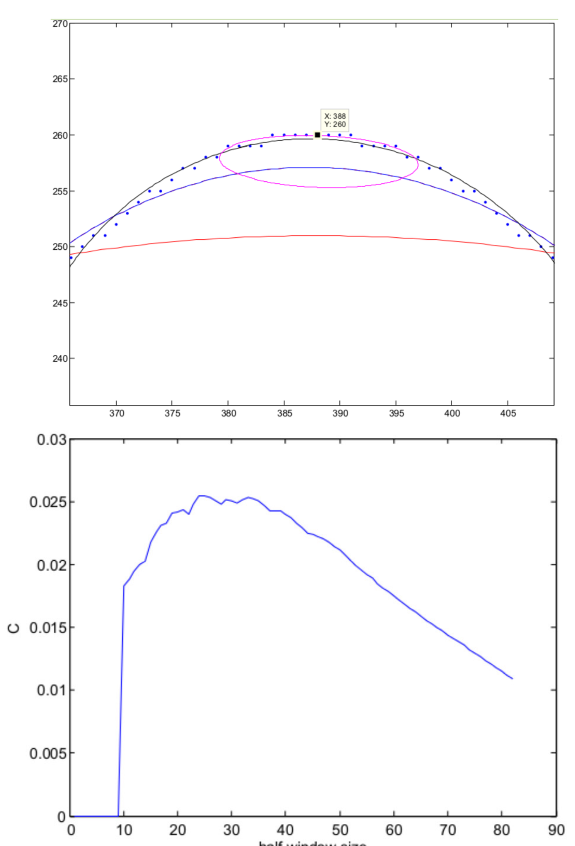
Proposed Approaches

IDEA: tortuosity is likely to be based on ophthalmologist's experience and it is hardly captured by a formula – hence classifier:



A Multiple-Window Approach for Digital Curvature Estimation

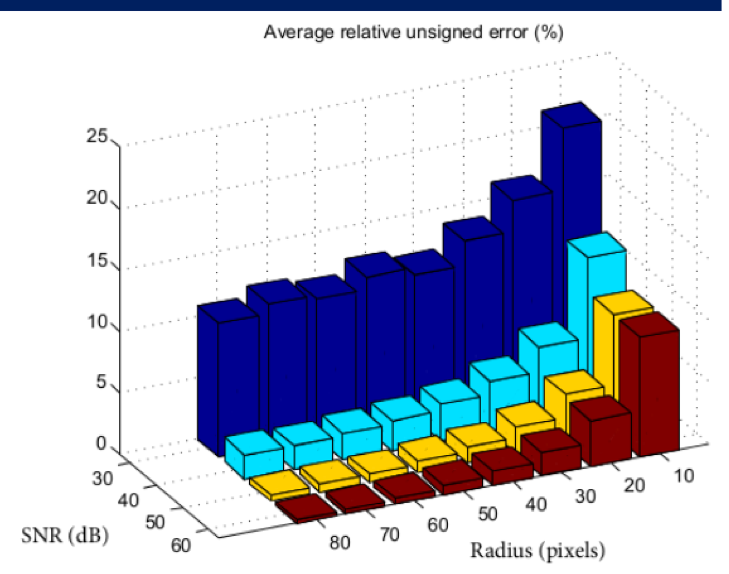
1. At each pixel, apply local ellipse fitting and line fitting using the smallest window size in a pre-defined range $R = [w_m, w_M]$;
2. Choose the best fitting function (ellipse-arc or line) based on the sum of squared errors;
3. If ellipse-arc is the best fitting function, compute the curvature using analytical derivatives on the estimated ellipse;
4. Repeat 1.-3. for all windows in R;
5. Select the maximum estimated curvature over all windows after median filtering to eliminate small, spurious peaks.



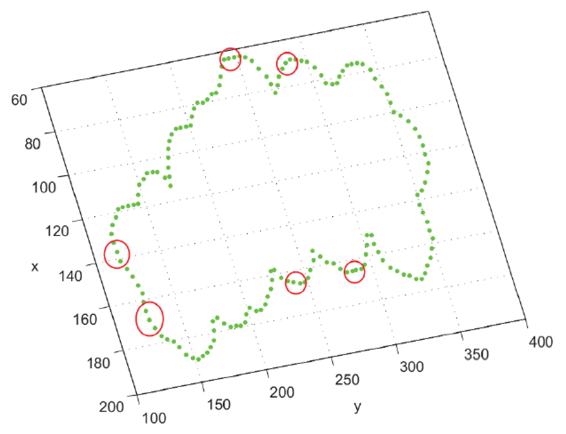
Experiments: Curvature Estimation

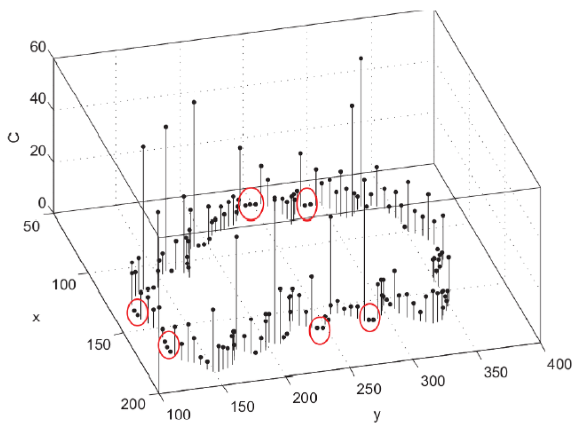
- Discretised circles with radii ranging from 10 to 80 pixels are corrupted by radial additive white Gaussian noise;
- Performance is quantified using the ARUE:

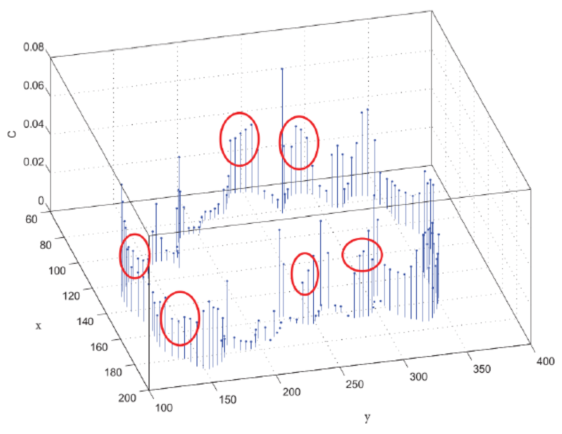
$$ARUE = \frac{1}{N}\sum_{i=1}^{N}\frac{\left|\frac{1}{r} - C_{est}(i)\right|}{\frac{1}{r}}$$



Comparison with Matas et al. method using fixed window size


Original boundary


Matas et al.


Proposed approach

Experiments: Corneal Nerves Images Classification

- Data set: 100 images, 4 levels of tortuosity, 3 ophthalmologists;
- Poor inter-observer agreement (< 50%), the consensus ground truth (CGT – 90 images) is used instead;
- 3 experiments:

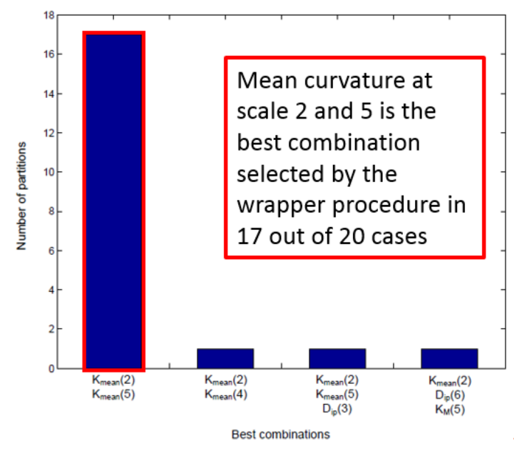
Association with CGT

Perfomance measures	MLOR	OSVM
Acc	84.44%	80.56%
Se	69.77%	61.94%
Sp	89.50%	86.86%
Ppv	69.75%	62.61%
Npv	89.48%	86.84%
MSE	0.3444	0.4222
MAE	0.3222	0.4000

Association with individual GT (Accuracy)

	AK	PH	SA	**MLOR**
AK	100%	76.67%	75%	**88.89%**
PH	**76.67%**	100%	73.89%	**76.67%**
SA	75%	73.89%	100%	**77.22%**

Are multiple scales effective? (MLOR)



Conclusions

- Trained with CGT and tested against each observer, our MLOR-based approach outperforms the best observer hold out (benchmark);
- Scale seems to play a role and a multi-scale approach is effective;
- Supervised approach instead of single formula for tortuosity estimation;
- New approach for digital curvature estimation;
- First to propose an automatic method capable of predicting more than 3 tortuosity levels.

References

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[3] Cruzat A., Pavan-Langston D., Hamrah P. "In vivo confocal microscopy of corneal nerves: analysis and clinical correlation". *In Seminars in ophthalmology*, vol. 25, No. 5-6, pp. 171-177, New York: Informa Healthcare (2010).

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