Vascular Assessment and Measurement Platform for Images of the REtina

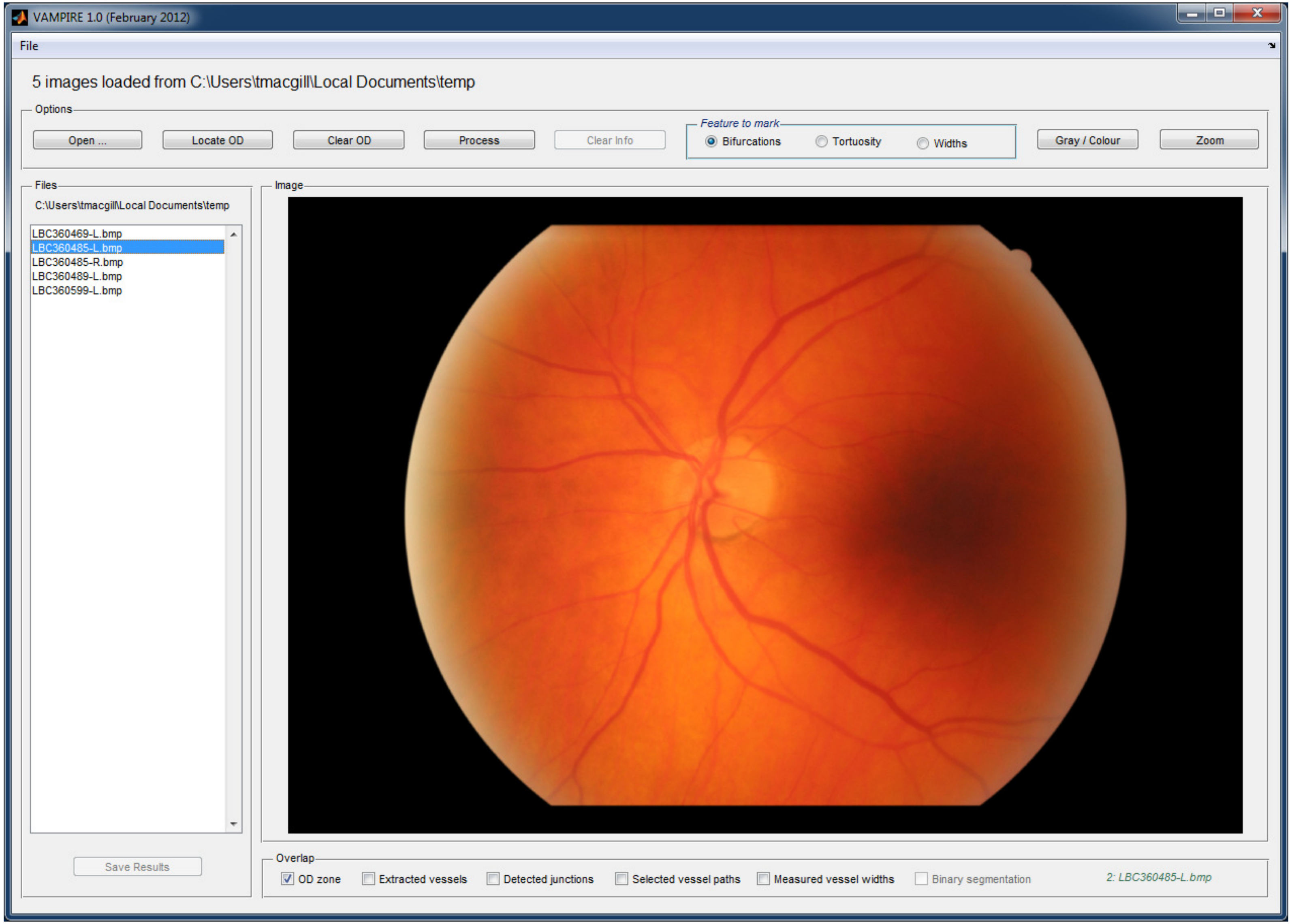
Vampire

Vascular Assessment and Measurement Platform for Images of the REtina

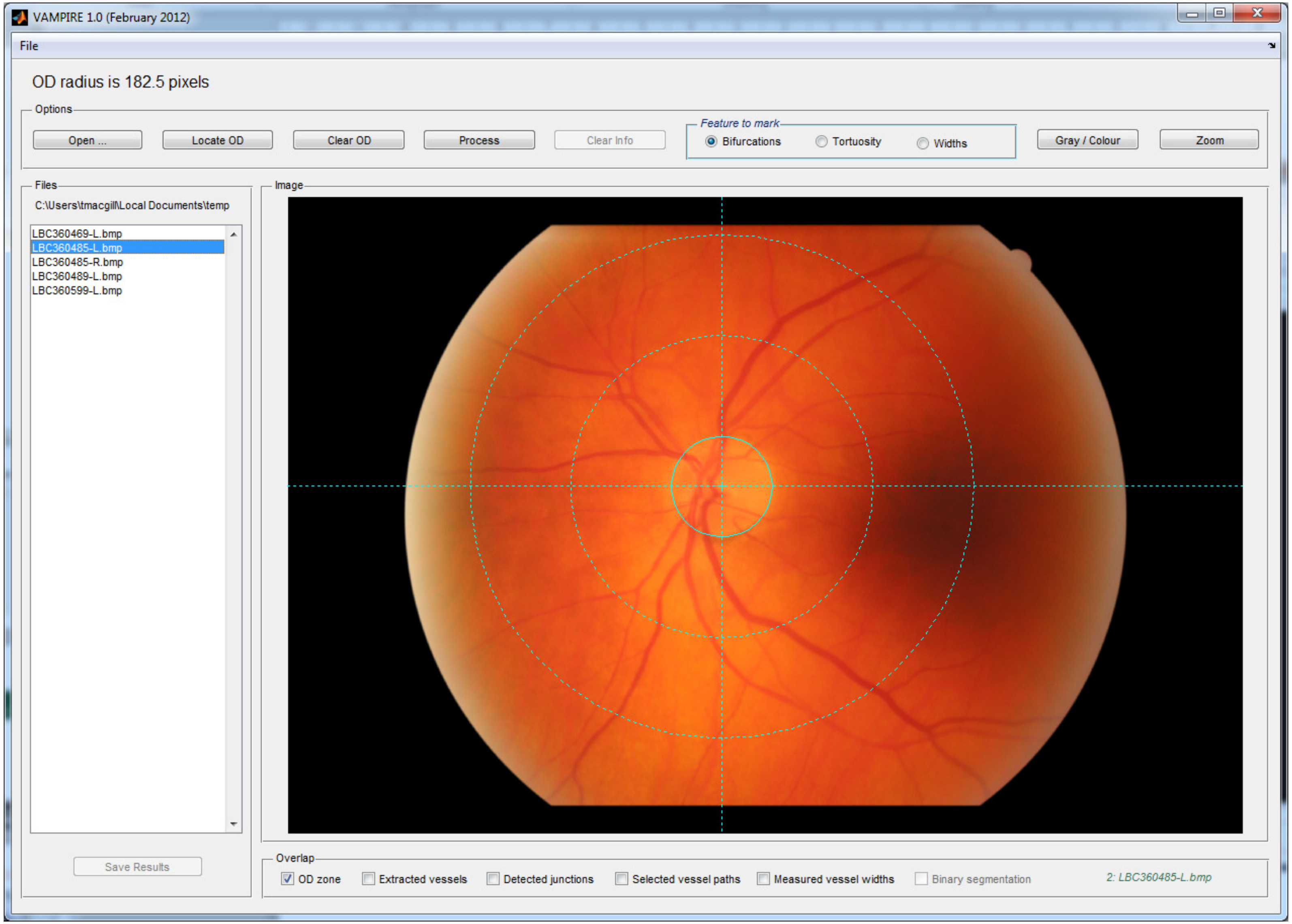
- consortium of 10 international research groups
- cluster of projects hinging on retinal image analysis
- software suite

- prototypes in Matlab mainly on Windows
- compile and run on Windows, Mac OS, Linux
- fundus images … scanning laser ophthalmoscope

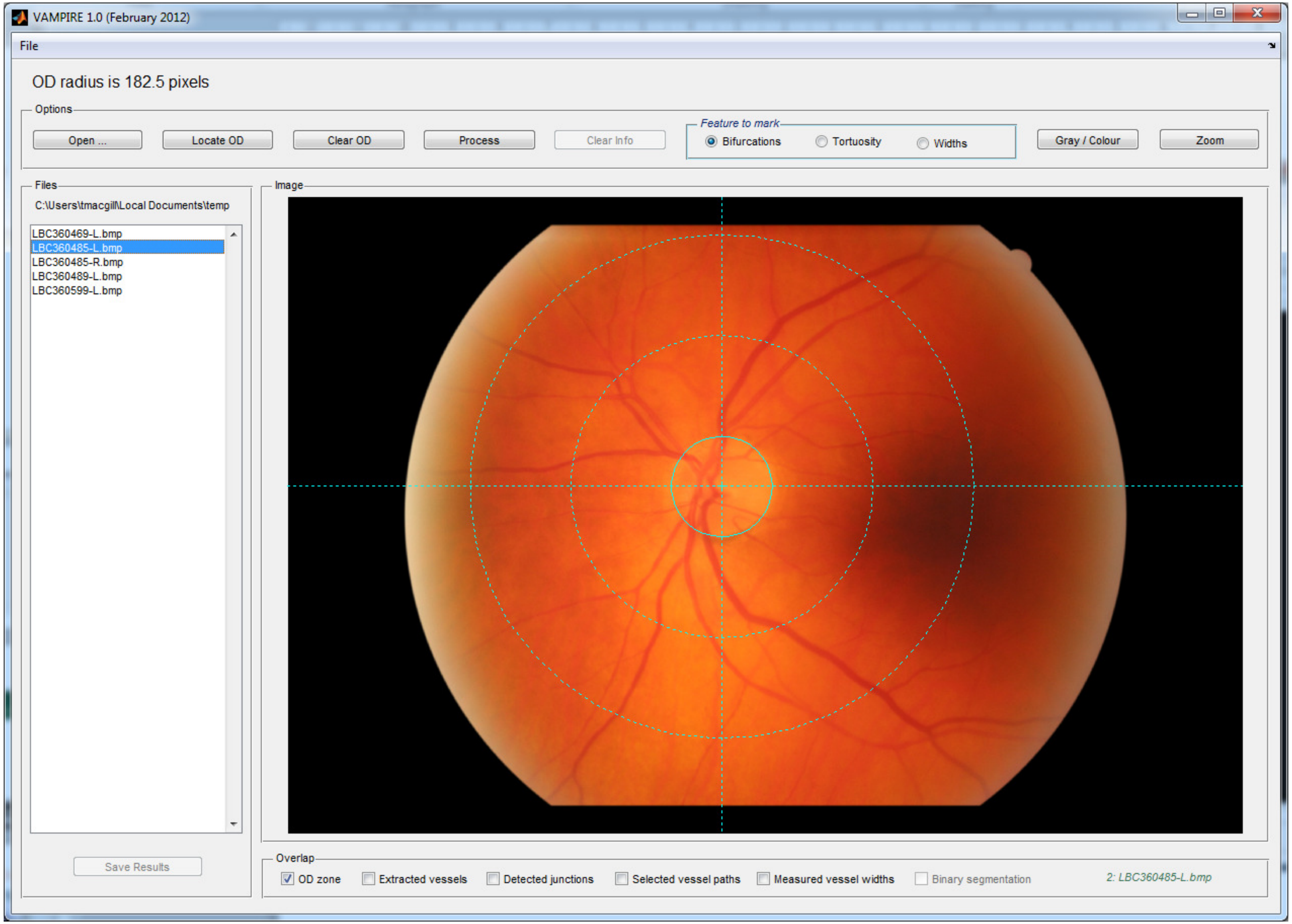
the VAMPIRE platform



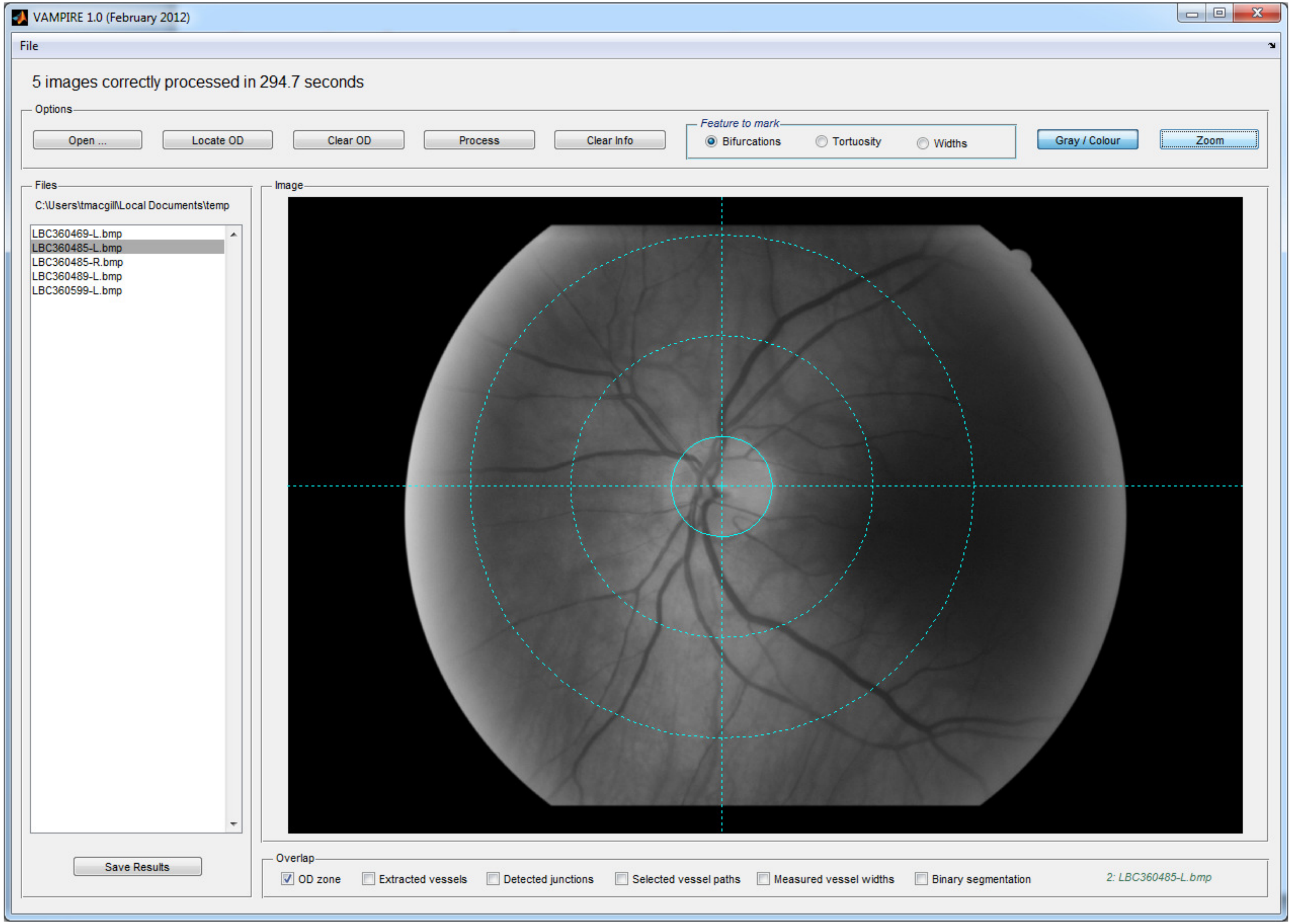
1. optic disc boundary detection



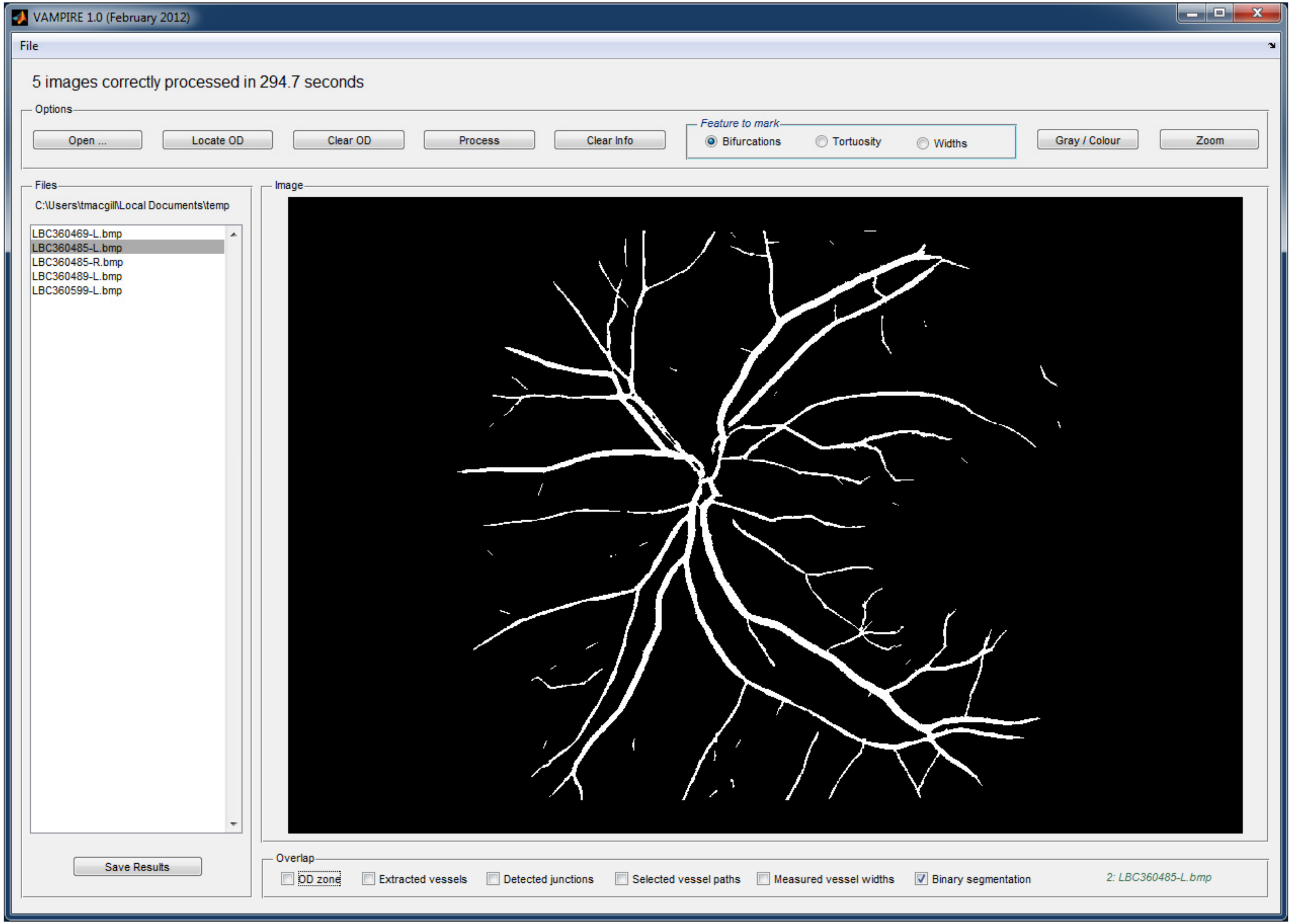
2. retinal vessel segmentation



2. retinal vessel segmentation – green channel



2. retinal vessel segmentation – binary map



2. retinal vessel segmentation – filtering and classification

Retinal Vessel Segmentation Using the 2-D Gabor Wavelet and Supervised Classification

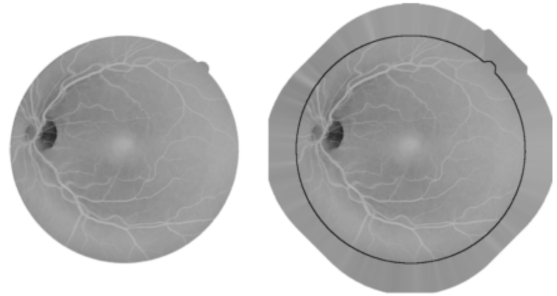
João V. B. Soares*, Jorge J. G. Leandro, Roberto M. Cesar Jr., Herbert F. Jelinek, and Michael J. Cree, *Senior Member, IEEE*

***Abstract*—We present a method for automated segmentation of the vasculature in retinal images. The method produces segmentations by classifying each image pixel as *vessel* or *nonvessel*, based on the pixel's feature vector. Feature vectors are composed of the pixel's intensity and two-dimensional Gabor wavelet transform responses taken at multiple scales. The Gabor wavelet is capable of tuning to specific frequencies, thus allowing noise filtering and vessel enhancement in a single step. We use a Bayesian classifier with class-conditional probability density functions (likelihoods) described as Gaussian mixtures, yielding a fast classification, while being able to model complex decision surfaces. The probability distributions are estimated based on a training set of labeled pixels obtained from manual segmentations. The method's performance is evaluated on publicly available DRIVE (Staal *et al.*, 2004) and STARE (Hoover *et al.*, 2000) databases of manually labeled images. On the DRIVE database, it achieves an area under the receiver operating characteristic curve of 0.9614, being slightly superior than that presented by state-of-the-art approaches. We are making our implementation available as open source MATLAB scripts for researchers interested in implementation details, evaluation, or development of methods.**

***Index Terms*—Fundus, Gabor, pattern classification, retina, vessel segmentation, wavelet.**

I. Introduction

OPTIC fundus [Fig. 1(a)] assessment has been widely used by the medical community for diagnosing vascular and nonvascular pathology. Inspection of the retinal vasculature may reveal hypertension, diabetes, arteriosclerosis, cardiovascular disease, and stroke [3]. Diabetic retinopathy is a major



(a) (b)

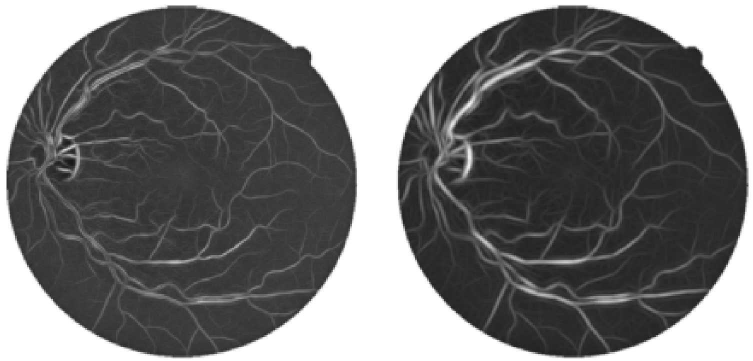
Fig. 1. Fundus image preprocessing for removing undesired border effects. (a) Inverted green channel of colored fundus image. (b) Preprocessed image with extended border. Original image limit is indicated for illustration.

to a year. Early recognition of changes to the blood vessel patterns can prevent major vision loss as early intervention becomes possible [5], [6].

To provide the opportunity for initial assessment to be carried out by community health workers, computer based analysis has been introduced, which includes assessment of the presence of microaneurysms and changes in the blood flow/vessel distribution due to either vessel narrowing, complete occlusions or new vessel growth [7]–[9].

An automatic assessment for blood vessel anomalies of the optic fundus initially requires the segmentation of the vessels

2. retinal vessel segmentation - accuracy



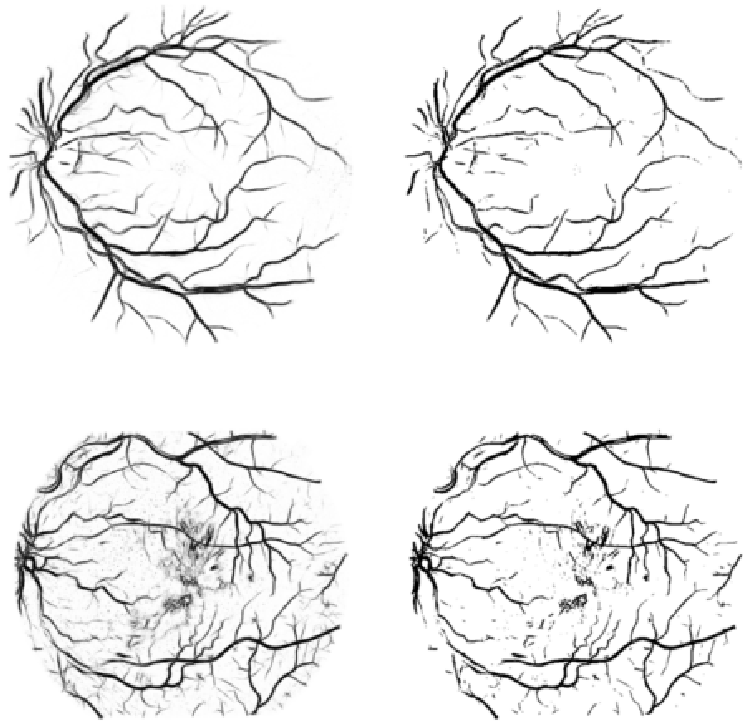
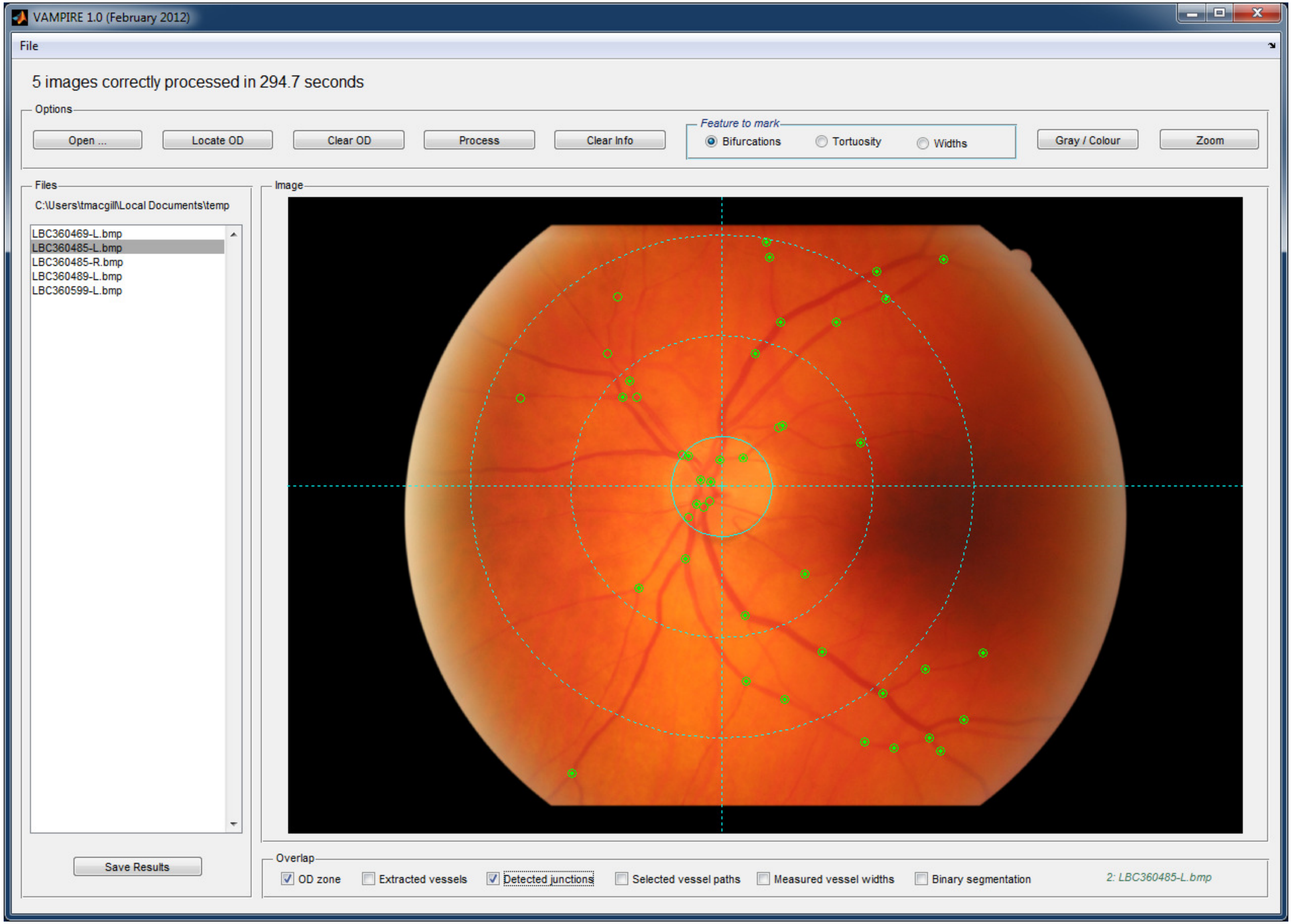


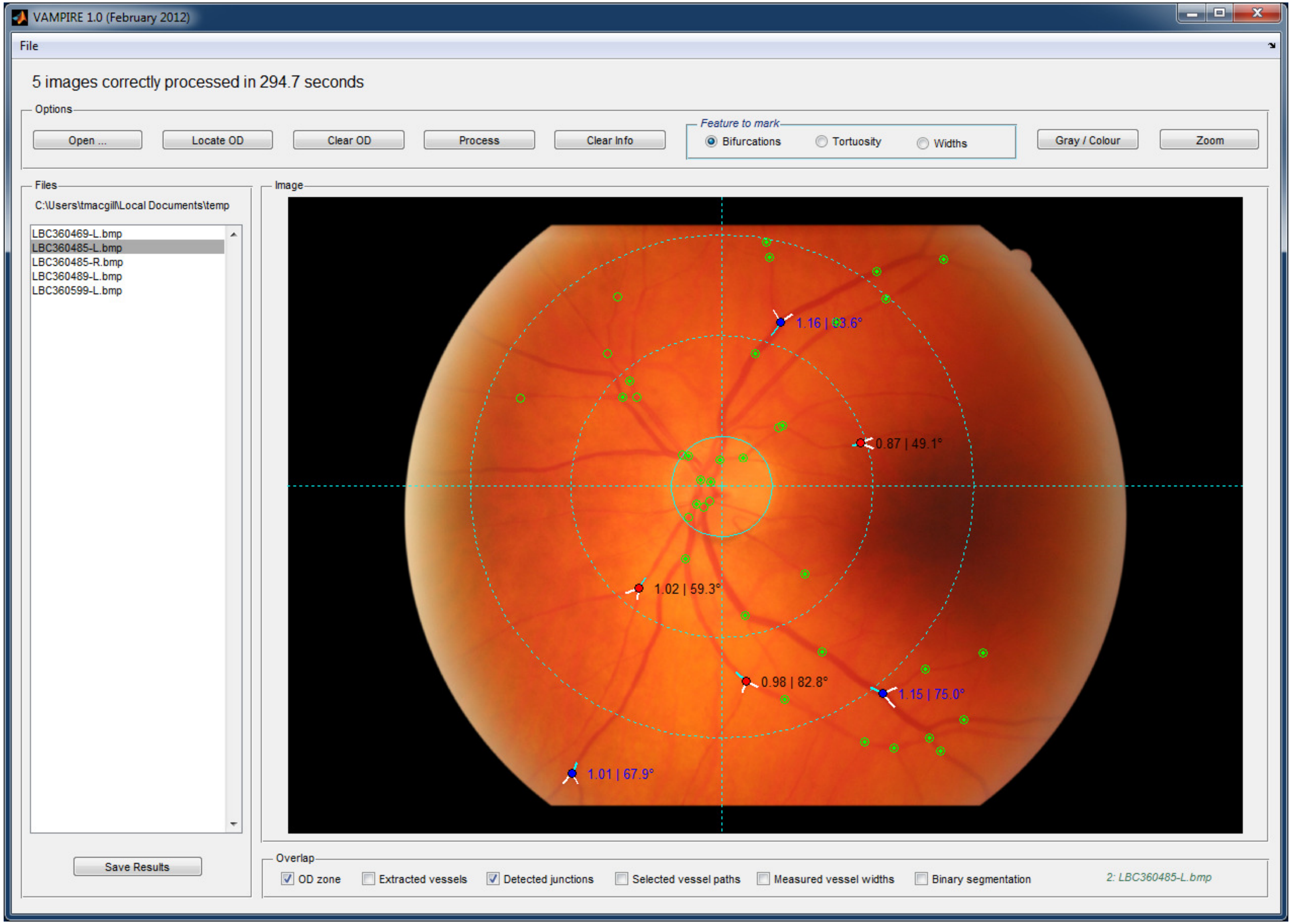
TABLE I
RESULTS FOR DIFFERENT SEGMENTATION METHODS AND A SECOND HUMAN OBSERVER. A_z INDICATES THE AREA UNDER THE ROC CURVE, WHILE THE ACCURACY IS THE FRACTION OF PIXELS CORRECTLY CLASSIFIED

Segmentation Method	Database			
	DRIVE		STARE	
	A_z	Accuracy	A_z	Accuracy
GMM, $k = 1$	0.9283	0.9218	0.9409	0.9243
GMM, $k = 5$	0.9546	0.9413	0.9618	0.9431
GMM, $k = 10$	0.9588	0.9447	0.9651	0.9467
GMM, $k = 15$	0.9605	0.9460	0.9666	0.9476
GMM, k = 20	**0.9614**	**0.9466**	**0.9671**	**0.9480**
$M_\psi(\mathbf{b}, 4)$	0.9312		0.9351	
Chaudhuri *et al.*	0.9103		0.8987	
Jiang *et al.*	0.9327	0.8911	0.9298	0.9009
Staal *et al.*	0.9520	0.9441	0.9614	0.9516
2nd. observer		0.9473		0.9349

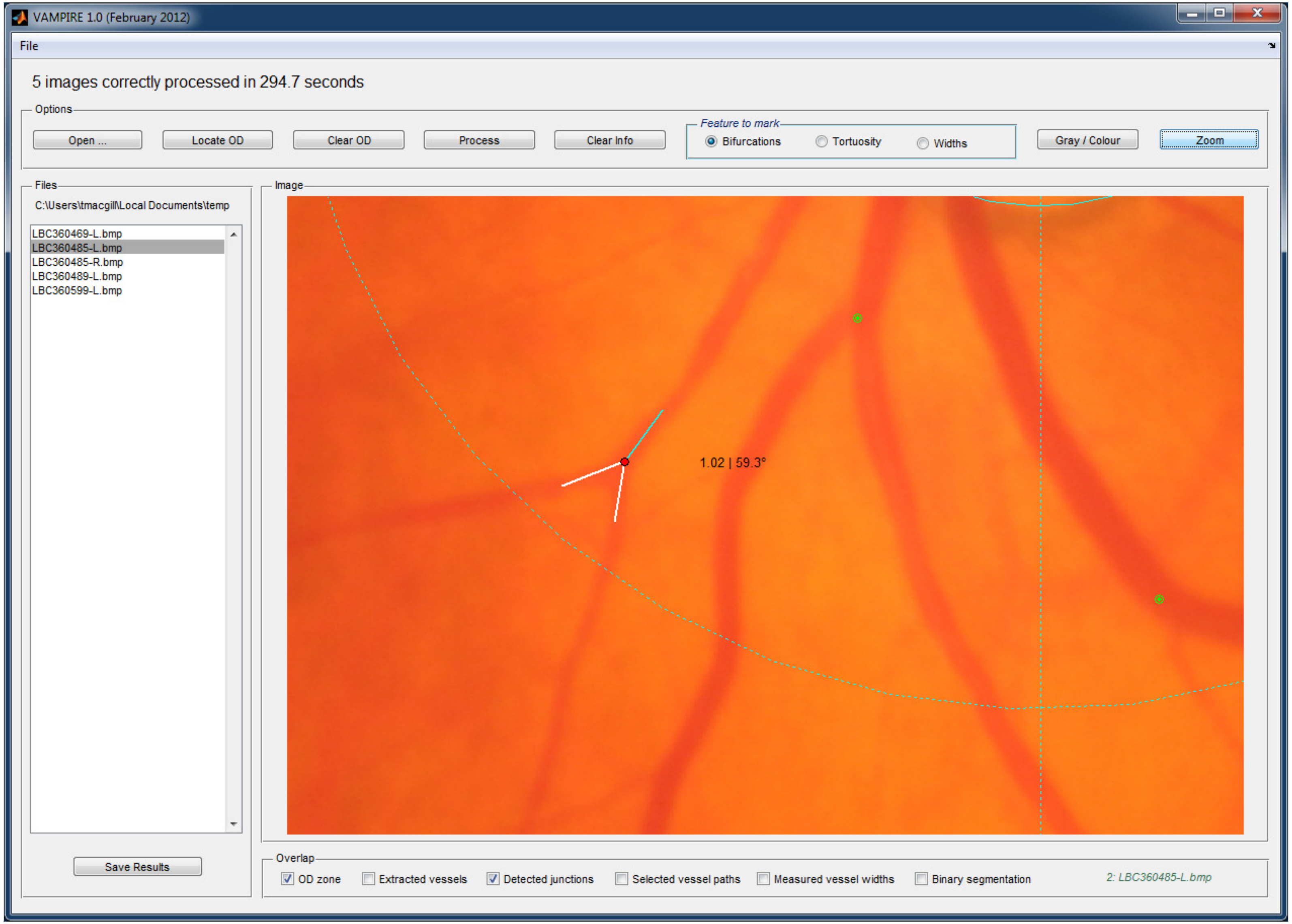
3. bifurcations - junction detection



3. bifurcations – measurements

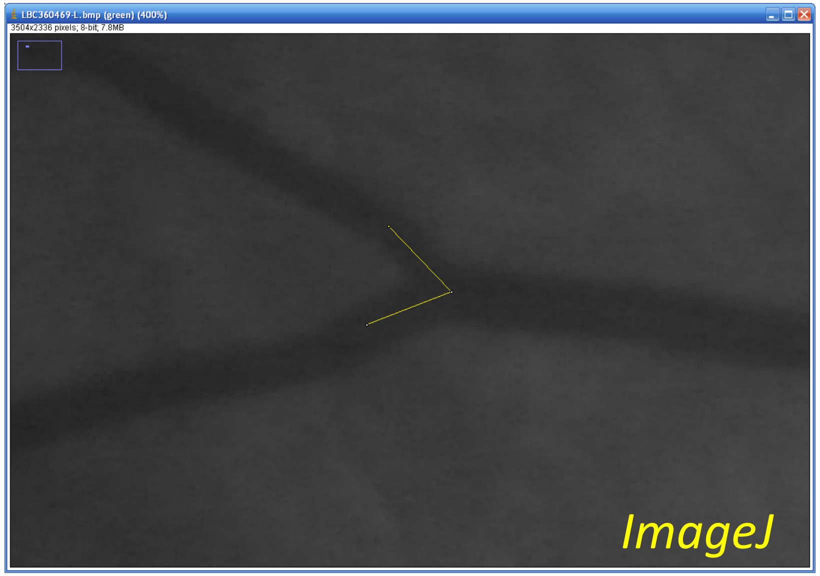


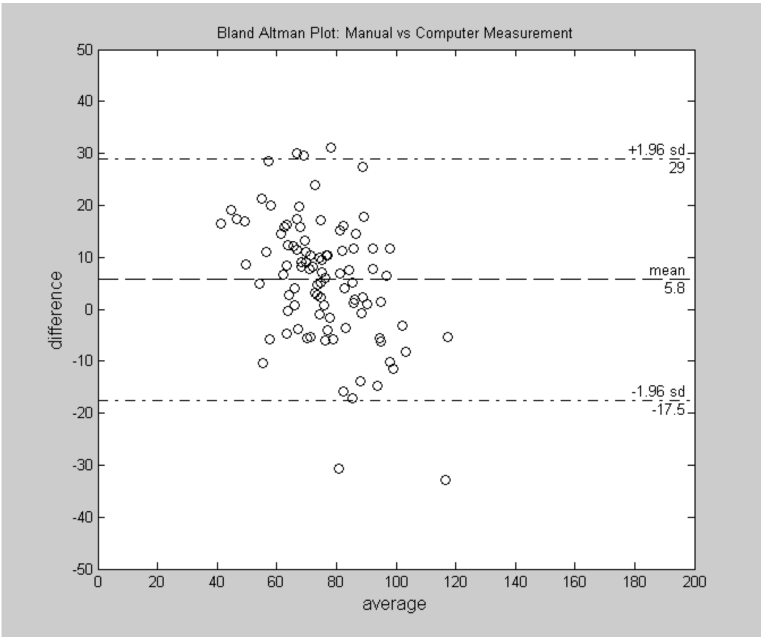
3. bifurcations – angle & coefficient

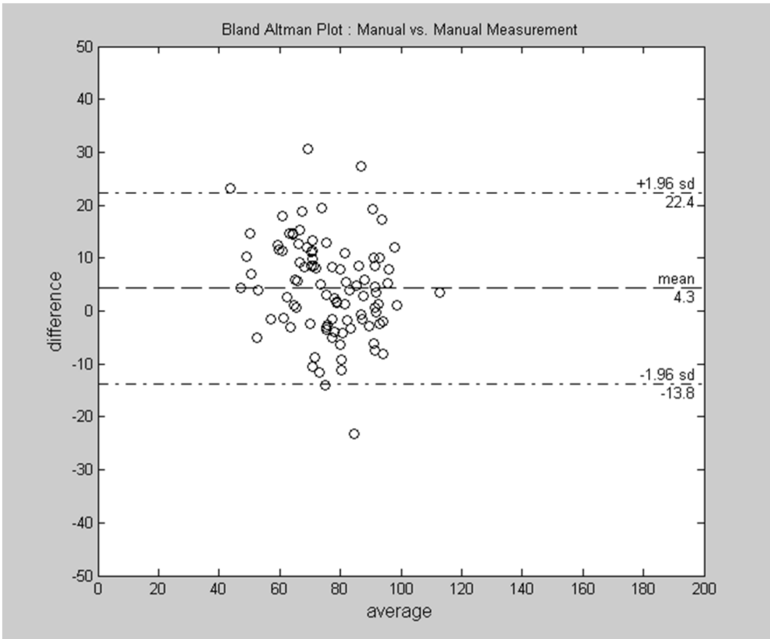


3. bifurcations – validation

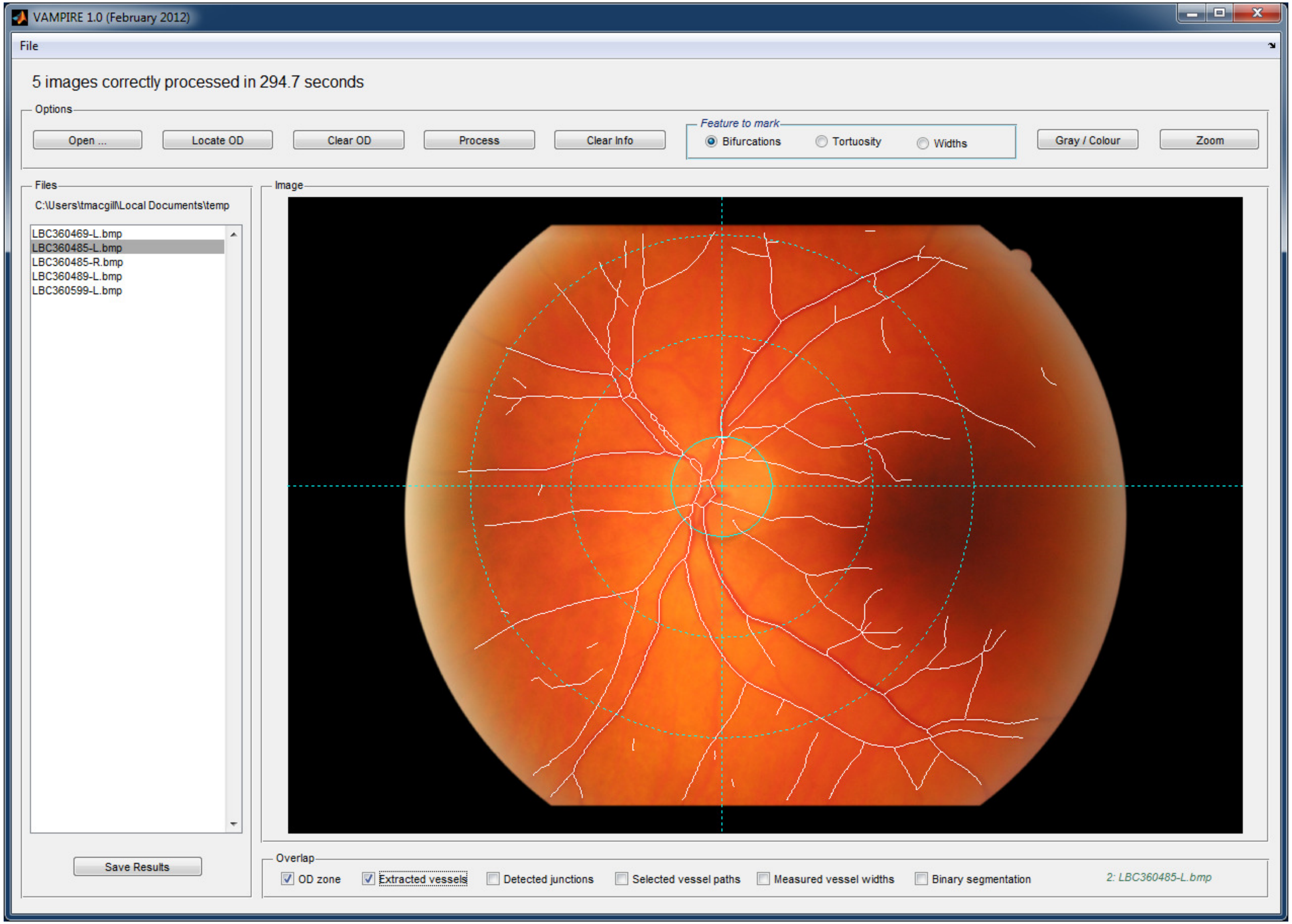
- mixture of arterioles and venules
- ~100 measurements
- manual vs manual
- manual vs VAMPIRE







4. tortuosity



4. tortuosity – curvature & thickness

IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 57, NO. 9, SEPTEMBER 2010 2239

Modeling the Tortuosity of Retinal Vessels: Does Caliber Play a Role?

Emanuele Trucco*, Hind Azegrouz, *Member, IEEE*, and Baljean Dhillon

***Abstract*—The tortuosity of retinal blood vessels is a diagnostic parameter assessed by ophthalmologists on the basis of examples and experience; no quantitative model is specified in clinical practice. All quantitative measures proposed to date for automatic image analysis purposes are functions of the curvature of the vessel skeleton. We suggest in this paper that curvature may not be the only quantity involved in modeling tortuosity, and that vessel thickness, or caliber, may also play a role. To support this statement, we devise a novel measure of tortuosity, depending on both curvature and thickness, and test it with 200 vessels selected by our clinical author from the public digital retinal images for vessel extraction database. Results are in good accordance with clinical judgment. Comparative experiments show performance similar to or better than that of four measures reported in the literature. We conclude that there is reasonable evidence supporting the investigation of tortuosity models incorporating more measurements than just skeleton curvature, and specifically vessel caliber.**

***Index Terms*—Automated, curvature, retinal, screening, tortuosity, vasculature properties.**

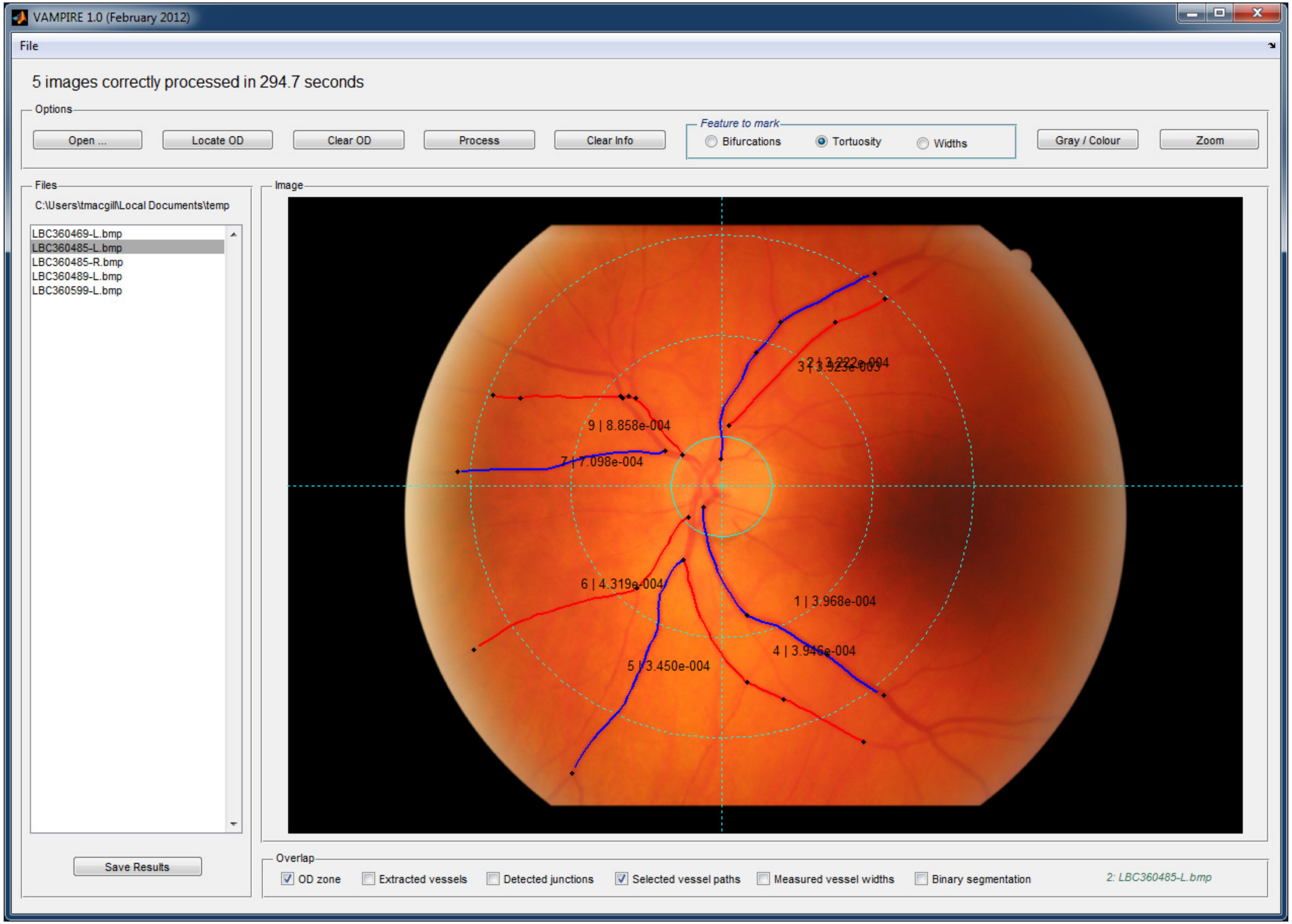
I. Introduction

A. Tortuosity and Its Clinical Relevance

HEALTHY retinal vessels run in smooth arcs, forming a tree-like network rooted in the optic dics; winding, twisted vessel, are instead a feature of many diseases, including retinopathy of prematurity (ROP), diabetic retinopathy, hypertension, conditions associated with hypoxia [1], and several genetic syndromes. *Tortuosity* is a qualitative parameter used by well [3]. It has been noted that using a grading scale to describe the retinal vasculature significantly improves inter- and intraobserver repeatability [4]. Furthermore, tortuous vessels can potentially inform us about the stresses imposed on the retinal vasculature, and its ability to respond to such stresses. In circulations outside the eye, vessel widening and elongation (leading to tortuosity) are known to be caused by high flow rates [5] and vascular congestion [6]; significant efforts have been put into defining the biophysical parameters needed to cause changes in vascular structure because of their relevance to conditions such as stroke [7]. The etiology of retinal vascular tortuosity can be captured by broad categories, including venous congestion, retinal ischemia, increased blood flow, and rare angiogenesis [8]. In contrast, much detail about the interaction between hemodynamic forces and layers of the vessel wall remains elusive. Mathematical models of angiogenesis have been reported by McDougall *et al.* [9] for tumors, but not, to our knowledge, for retinal vessels. Identification of the mutations responsible for conditions such as familial retinal arteriolar tortuosity [8] could give important information about retinal vessel structure needed for normal circulation. Similarly, knowledge about the amount of sheer stress generated by a given flow rate and vessel curvature would allow one to link degrees of tortuosity with degrees of force acting on the epithelium, which in turn can be associated with cellular responses involving gene transcription and release of mediators [10].

The study and measurement of tortuosity are relevant for both diagnostic and modeling purposes. The key motivation for our

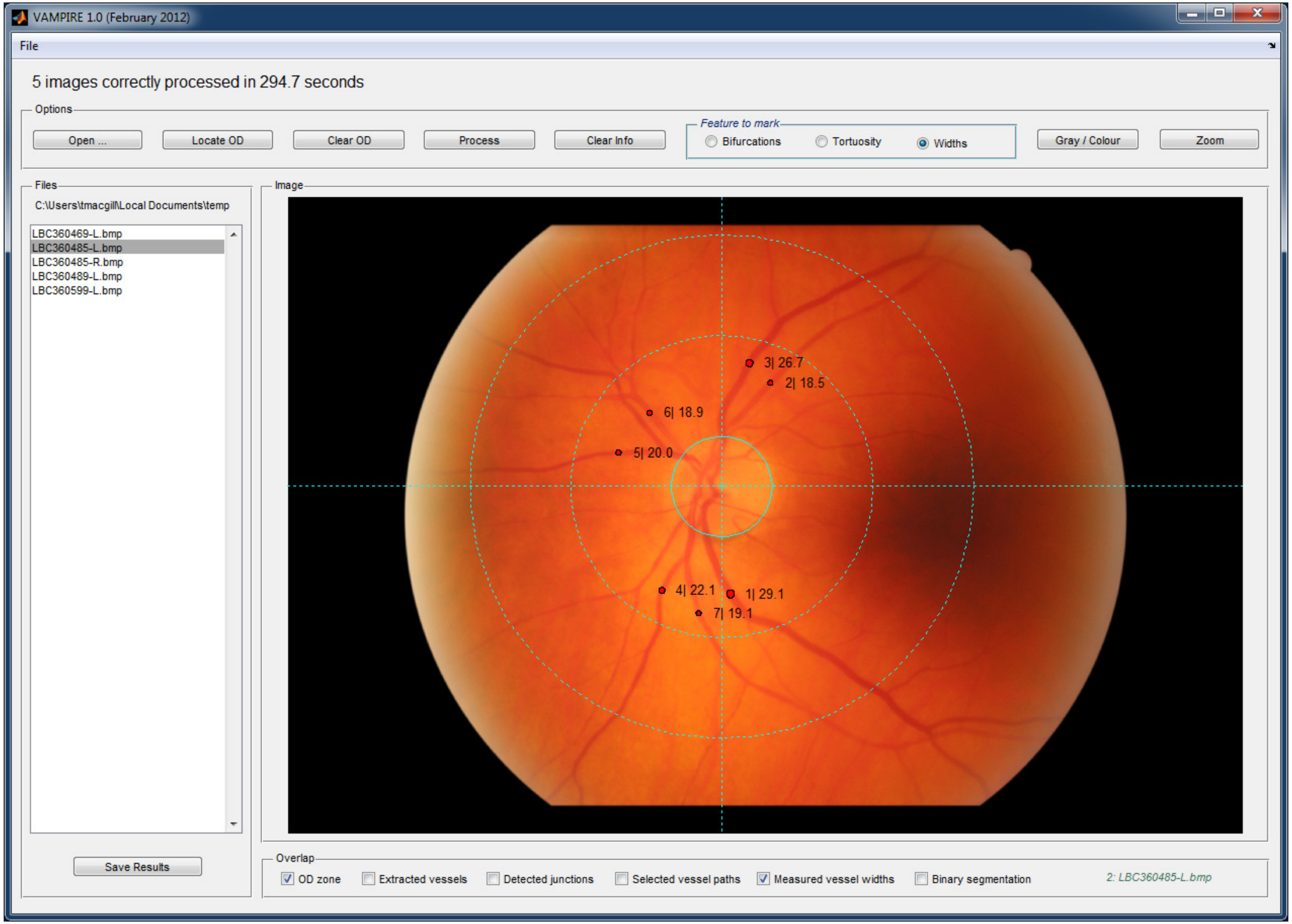
4. tortuosity – measurements



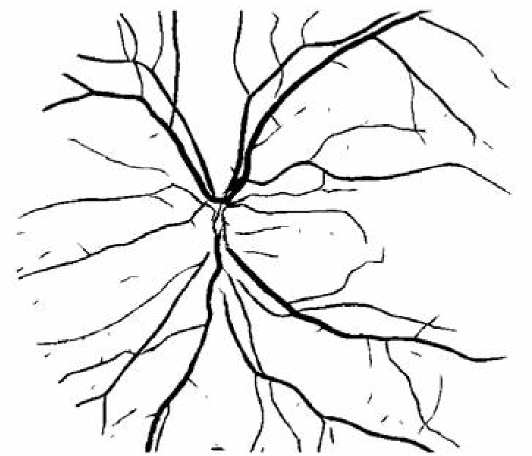
4. tortuosity – validation

- mixture of arterioles and venules
- ~1000 measurements
- 3 manual gradings
- manual vs VAMPIRE

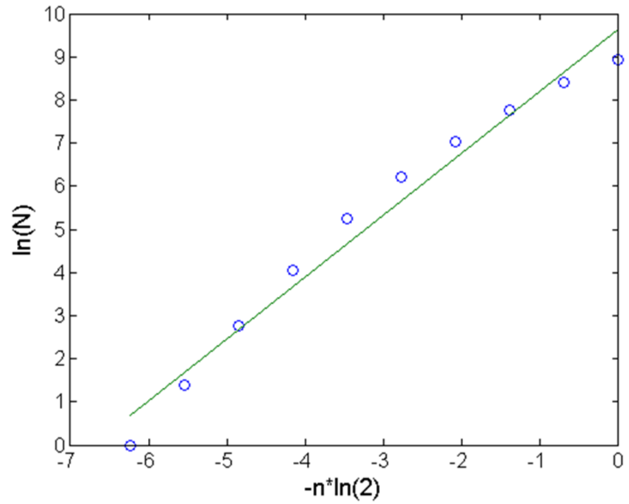
4. vessel caliber



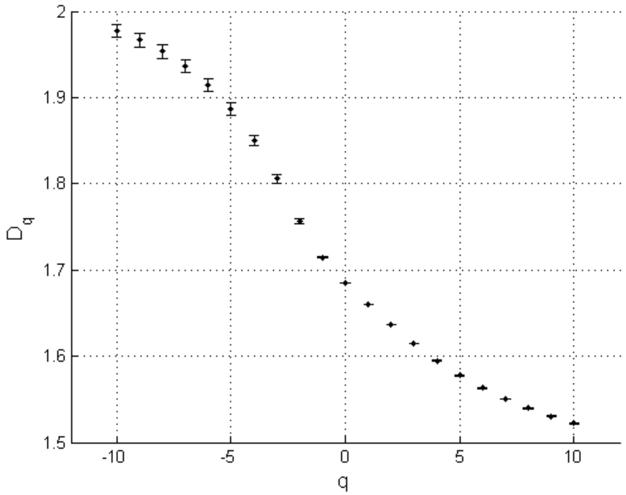
5. fractal analysis



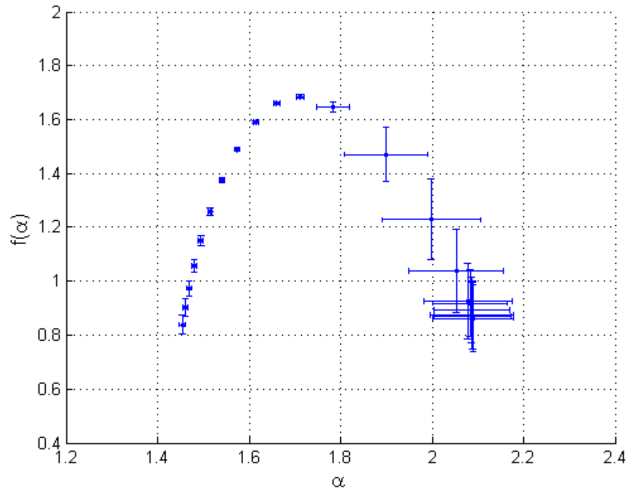
branching complexity?



box counting - slope yields - single/mono FD



generalized dimension spectrum – multiple FD's



f(α) spectrum

5. fractal analysis - mono

Current Eye Research
2002, Vol. 24, No. 4, pp. 274–280

0271-3683/02/2404-274$16.00

Fractal analysis of region-based vascular change in the normal and non-proliferative diabetic retina

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Departments of [1]Ophthalmology, [2]Biological Structure, and [3]Electrical Engineering, University of Washington, Seattle, USA

Abstract

Purpose. Evaluation of normal and abnormal vascular pattern in the human retina using a novel method: quantitative region-based fractal analysis.

Methods. Binary (black/white) vascular patterns of the human retina originating at the optic disc were obtained by semi-automatic computer processing of digital images from 60-degree fundus fluorescein angiography of 5 normal eyes and 5 eyes with non-proliferative diabetic retinopathy (NPDR). As determined by image resolution, vascular patterns included vessels with diameters ≥50 µm and excluded small vessels and capillaries. The density of linearized (i.e., skeletonized) vascular patterns in the macular region versus paramacular region (termed "region-based" linearized vascular pattern) was quantified with the fractal dimension (D_f) and confirmed by grid intersection (ρ_v).

Results. By region-based quantification, D_f and ρ_v were significantly higher in the normal macular region than in the

Introduction

The goal of this study was to investigate the effectiveness of fractal analysis for quantitative characterization of the vascular patterns that are altered during the early stages of human retinal disease. We therefore obtained binary (black/white) vascular patterns originating at the retinal optic disc (Fig. 1) by computer processing of images from 60° clinical fluorescein angiography of normal patients or patients diagnosed with non-proliferative diabetic retinopathy (NPDR). As determined by spatial resolution of the angiography, capillaries and smaller vessels were excluded from this retrospective fractal analysis. The image-extracted vascular patterns used for the novel region–based analysis contained only arteries and veins of diameter ≥ approximately 50 µm.

Preliminary qualitative observations of the linearized (skeletonized) vascular patterns in the normal and NPDR macula suggested that vascular morphology had already changed by this relatively early stage of retinal disease (Fig. 2). For the region-based quantification of linearized vascular

5. fractal analysis - multi

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 25, NO. 8, AUGUST 2006

Multifractal Analysis of Human Retinal Vessels

Tatijana Stošić and Borko D. Stošić*

***Abstract*—In this paper, it is shown that vascular structures of the human retina represent geometrical multifractals, characterized by a hierarchy of exponents rather then a single fractal dimension. A number of retinal images from the STARE database are analyzed, corresponding to both normal and pathological states of the retina. In all studied cases, a clearly multifractal behavior is observed, where capacity dimension is always found to be larger then the information dimension, which is in turn always larger then the correlation dimension, all the three being significantly lower then the diffusion limited aggregation (DLA) fractal dimension. We also observe a tendency of images corresponding to the pathological states of the retina to have lower generalized dimensions and a shifted spectrum range, in comparison with the normal cases.**

***Index Terms*—Blood vessels, fractals, multifractals, retina.**

I. Introduction

OVER the past decade, there have been several attempts [1]–[6] in the direction of employing the fractal dimension as a measure for quantifying the "state" of human retinal vessel structures (considered as geometrical objects), with the expectation that such analysis may contribute to automatic detection of pathological cases, and, therefore, to computerization of the diagnostic process. While this is certainly a valid question with possibly high impact on real world diagnostic issues, there are some issues that should be addressed before such investigations may prove useful for the standard clinical practice. First, the fact that retinal vessels represent "finite size" realizations of a fractal growth process, imposes questions about how exactly should one go about measuring the fractal dimension of a particular instance (e.g., an electronic image of a retinal

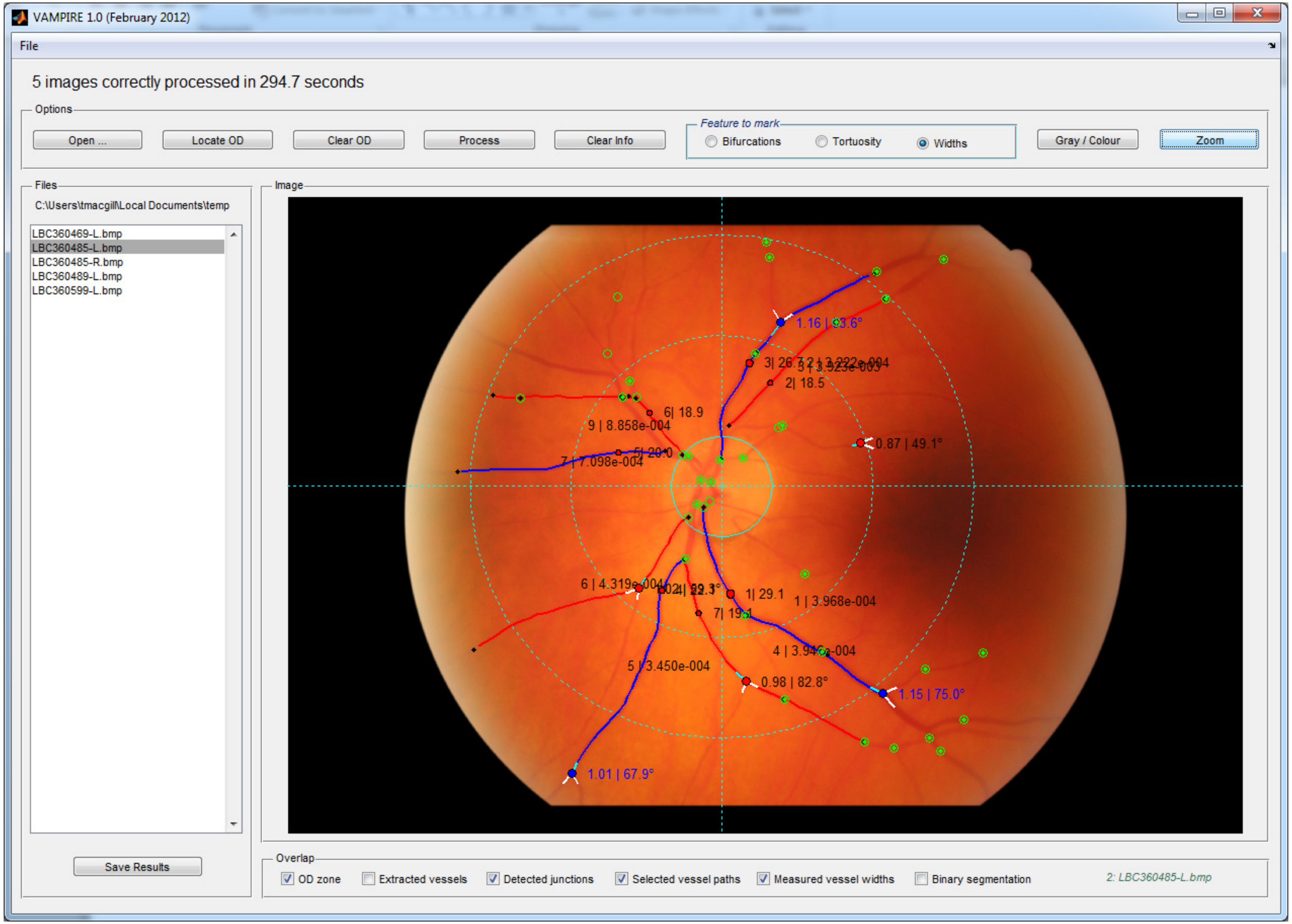
works are only remotely related to established concepts of multifractality, and the corresponding commonly accepted procedures for its measurement (see, e.g., [7]–[12] and references therein).

In this paper, we concentrate on the latter of the above issues, that is, we show that the human retinal vessel structures are geometrical multifractals, characterized by a hierarchy of exponents rather then a single fractal dimension. We analyze a number of retinal images from the STARE database [13], corresponding to both normal and pathological states of the retina. In all cases, we find clearly multifractal behavior. The capacity (or box counting) dimension is always found to be larger then the information (or Shannon) dimension, which is in turn always larger then the correlation dimension. In all cases, the observed values of the capacity dimension were significantly lower then the diffusion limited aggregation (DLA) fractal dimension, which has been considered in earlier works [1], [2], [6] as the primary model relevant for the phenomenon at hand. It is also found that images corresponding to pathological cases tend to have lower generalized dimensions, as well as a shifted spectrum range, in comparison with the normal cases.

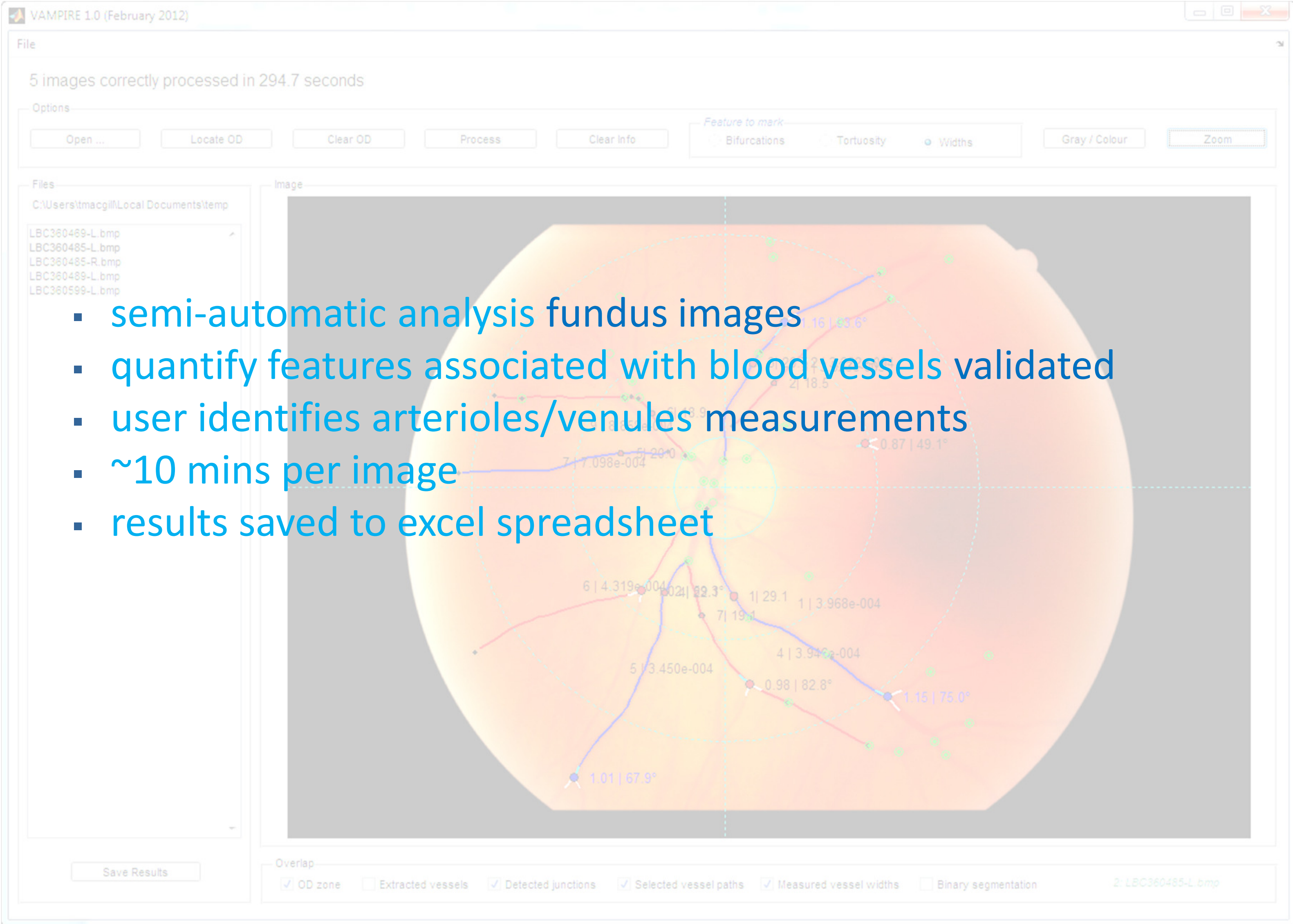
II. Multifractal Analysis

In contrast to simple fractals (or monofractals), multifractals are characterized by a hierarchy of exponents, rather then a single fractal dimension. More precisely, multifractals may be viewed as a union of intervowen monofractals, embedded into each other. The word "hierarchy" here refers to different mem-

the VAMPIRE platform



the VAMPIRE platform



- semi-automatic analysis fundus images
- quantify features associated with blood vessels validated
- user identifies arterioles/venules measurements
- ~10 mins per image
- results saved to excel spreadsheet

Vampire & biobank uk

- application to access subset of UKBiobank fundus images
- trained group of users (5-10) VAMPIRE software
- run on UKBiobank systems Windows
- roll out to entire set fundus images

Clinical research and VAMPIRE

Stroke

- 253 stroke patients (129 lacunar, 124 cortical, mean 68y) fundus images
- venules wider in patients with lacunar stroke vs cortical stroke
- fractal dimensions ↓ lacunar stroke suggests loss of branching complexity
- venular disease may play a role in the pathophysiology of lacunar stroke

LBC 1936

- investigating the determinants of differences in cognitive ageing
- cognitive tests, medical history, social background, psychosocial questionnaires, physical exam
- collect blood samples, MR brain scans and retinal fundus images
- retinal abnormalities as biomarkers for cerebral microvasculature and relationship to cognitive ability level

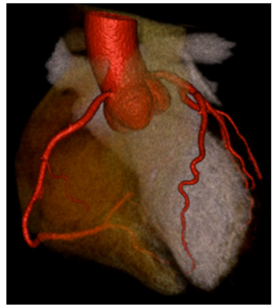
Related projects

Retinal biomarker for genetic discovery (2012-2015)

- Dundee (Computing) and Edinburgh (CRIC)
- Funded by the Leverhulme Trust

Wide-field retinal scanning in diabetes and cardiovascular disease as a marker of cardiovascular and neurological impairment (2012-2015)

- Dundee (Computing, Radiology), Edinburgh (CRIC) and OPTOS
- Funded by SINAPSE and OPTOS plc



Summarization of SLO angiographic sequences (2010-2014)

- OPTOS machines
- Dundee, Jules Stein Eye Research institute, LA, USA
- Ischemia detection
- Funded by EPSRC (DTA) and OPTOS plc