SEGMENTATION AND ANALYSIS OF RETINAL VASCULAR TREE FROM FUNDUS IMAGES PROCESSING

Sandra Morales[1], Valery Naranjo[1], Jesús Angulo[2], Juan José Fuertes[1] and Mariano Alcañiz[1,3]

[1]*Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano Universitat Politècnica de València, I3BH/LabHuman, Camino de Vera s/n, 46022 Valencia, Spain*

[2]*Centre de Morphologie Mathématique, Mathématiques et Systèmes, MINES Paristech, Paris, France*

[3]*Ciber, Fisiopatología de Obesidad y Nutrición (CB06/03), Instituto de Salud Carlos III, Madrid, Spain*

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Abstract: From a fundus image, the system proposed in this paper automatically detects retinal vessels and measures some geometrical properties on them such as caliber and bifurcation angles. Its goal is to establish objective relations between different vessels, thus being able to determine cardiovascular risk or other diseases, as well as to monitor their progression and response to different treatments. The proposed approach is mainly based on mathematical morphology although also incorporates curvature evaluation for the detection of retinal vascular tree. This method has been validated on a public database improving the results of previous published methods.

1 INTRODUCTION

Retinal vasculature is able to indicate the status of other vessels of the human body. Classically, its study is included in the standard screening of any patients with cardiovascular risk and other diseases in which the vessels may be altered inasmuch as it is a non-invasive or minimally invasive procedure.

Nowadays, due to high resolution of digital fundus images, they can be automatically processed providing invaluable help to clinicians in diagnosis and disease prevention. Specifically, a system capable of detecting the retinal vessels and measuring some geometrical properties has been developed from a fundus image. Vascular changes produced in systemic diseases usually induce particular modifications in the vessels, such as changes in the angle of intersection between arteries and veins, and changes in the vessel calibers. Based on these facts, the goal of the proposed system is to establish objective relations between the different vessels, to determine cardiovascular risk or other diseases, as well as to monitor progress and response to different treatments. This tool has been initially applied in a study carried out by the Department of Pediatrics of General Hospital of Valencia about the retinal microvascular architecture of children with low birthweight, analyzing the relationship between the measurements obtained in these children and diseases such as hypertension and cardiovascular problems in adult life, thus using their results as a prognostic marker for this type of pathology.

At first, a segmentation process to characterize any retinal morphological changes is necessary. Afterwards, detected vessels must be labeled as a means to be able to perform desired measures on them and to quantify these changes.

The mainly methodology proposed in this paper is, above all, focused on mathematical morphology although also incorporates curvature evaluation to get a correct detection of retinal vascular tree.

2 SEGMENTATION METHOD

Although fundus images are RGB images, in the present work we draw on monochrome images obtained from the green band which provides a improved visibility of retinal blood vessels.

The segmentation method presented in this paper is based on mathematical morphology and curvature evaluation for the detection of retinal vascular tree. Mathematical morphology (Soille, 2003) is a non-linear image processing methodology based on minimum and maximum operations whose aim is to extract relevant structures of an image. This is achieved by probing the image with another set of known shape

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called structuring element (SE).

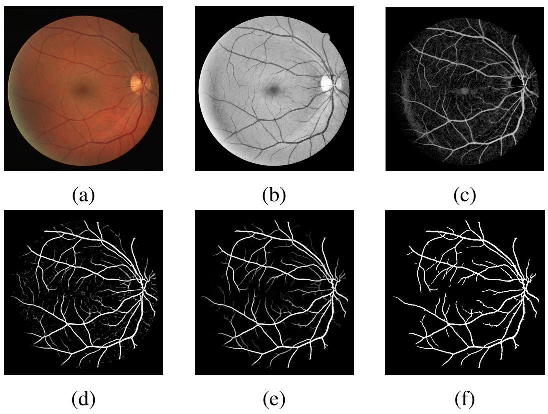
First, a small opening, using a disc of radius 1 as SE, is performed on the enhanced green component image to fill in any gaps of the vessels which could provoke errors in segmentation. To enhance the image a local shade correction (Walter and Klein, 2002) is applied.

Then, a dual top-hat, with a SE larger than the biggest vessel, is applied with the goal of extracting all of them and eliminating structures with high curvature that are not vessels, as occurs in the optic disc.

After that, to highlight the vessels on the background, the next steps are followed. Principal curvature is calculated as the maximum eigenvalue of the Hessian matrix (Martinez-Perez et al., 2007). Subsequently, a linear opening by reconstruction is applied to reconstruct the principal curvature from a supremum of openings which were calculated using a line of size 31 as SE every 15°. This operation removes any structure smaller than this SE in any orientation obtaining a cleaner background.

Finally, to binarize the resulting image a k-means clustering (MacQueen, 1967) is used with a k value equals to 3. Two of the three obtained clusters are defined as vessel. Three classes are requiered because thick and thin vessels can be very different.

Figure 1 shows the resulting images of the mentioned method.



(a) (b) (c) (d) (e) (f)

Figure 1: Segmentation steps: (a) Original fundus image, (b) Green component enhancement, (c) Dual top-hat filtering, (d) Principal curvature, (e) Opening by reconstruction and (f) k-means clustering (segmented image).

3 RETINAL TREE LABELING

Retinal vascular tree labeling is focused on obtaining the skeleton of vascular tree, detecting significant points and a tracking process.

The skeleton of the vascular tree is obtained by a thinning process from the segmented binary image (Soille, 2003). After, a pruning process is applied to eliminate possible spurs and to avoid multiple paths that are inherent in a 8-connected boundary.

In a vascular tree skeleton there are three types of significant points and all of them must be detected: terminal, bifurcation and crossing points (Martinez-Perez et al., 2002). To locate the terminal and bifurcation points the hit-or-miss transform is utilised. The hit-or-miss transform is a binary morphological operation that can be used to look for particular patterns in an image (Soille, 2003). Figure 2 shows the SEs used to detect these points on a skeleton. 1's define the set of pixels that should match the foreground and 0's the background. Notice that all of them must be used in all its orientations, one every 90^o. On the other hand, to detect the crossing points it will be necessary a manual intervention due to there are some of them that are incorrectly defined as bifurcation points.

1		
0	1	
1	0	1

(a)

	1	
	1	
1	0	1

(b)

	1	
1	1	
		1

(c)

0	1	0
0	0	0

(d)

Figure 2: Structuring elements used to detect significant points: (a-c) bifurcation points and (d) terminal points.

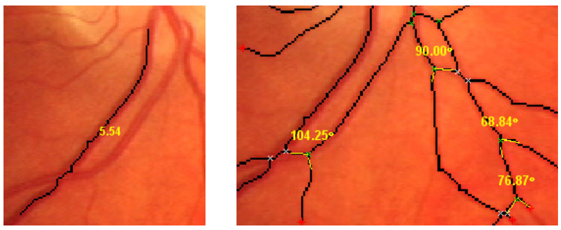
The tracking purpose is to analyze the direction of every pixel of the skeleton and to identify which pixels belong to each branch. The method used is proposed in (Martinez-Perez et al., 2002). The algorithm is able to specify the direction of any skeleton point from a starting point. In order to keep the relation information between the branches, a determinated numbering scheme is employed.

4 GEOMETRIC MEASURES

Certain geometric measurements of blood vessels can help to establish whether they have undergone morphological changes over time and facilitate diagnose illness. We focus on next parameters due to the fact that they have particular interest for the early hypertension detection:

Vessel Caliber. Is equal to two times the average of the geodesic distance calculated from the skeleton points of the branch to the edge of the corresponding vessel. (3a).

Bifurcation Angle. Angle formed by the daughter branches for each bifurcation point. The branches are fitted for straight lines by least-squares into a circular window centered on these points (3b).



(a) (b)

Figure 3: Measures: (a) Caliber and (b) Bifurcation angles.

5 RESULTS

To validate the segmentation, our method results have been compared with a public database of hand-segmented images. In DRIVE database (Staal et al., 2004) original images and the images manually segmented by two different specialists are included. The first-observer images are taken as reference (gold standard) to calculate similarity degree between them and our segmentation. The segmented images by the second observer also has been compared with the gold standard in order to note that there are also differences between both experts.

The performance of the method has been evaluated based on three concepts: accuracy (Ac) and true positive (TPF) and false positive (FPF) fractions. In table 1 these results can be observed. In summary, the average values obtanained by the proposed method are: Ac=0.9417, TPF=0.6570 and FPF=0.0166.

On the other hand, in (Niemeijer et al., 2004) a study about the accuracy of different vessel segmentation methods was carried out on the same database. This study compared several approaches: matched filter (Chaudhuri et al., 1989), scale-space analysis and region growing (Martinez-Perez et al., 1999), mathematical morphology and curvature estimation (Zana and Klein, 2001), verification-based local thresholding (Jiang and Mojon, 2003) and pixel classification (Niemeijer et al., 2004). Table 2 shows a comparison between the aforementioned methods and ours.

We can conclude that our method has achieved a higher accuracy ratio and its false positive fraction is, even, lower than the second observer fraction.

Table 1: Comparison between the results of the proposed method and the 2^{nd} observer (average values and standard deviations) regarding the gold standard.

	Proposed method	**2^{nd} observer**
Ac	0.9417 (0.0076)	0.9473 (0.0048)
TPF	0.6570 (0.0668)	0.7757 (0.0596)
FPF	0.0166 (0.0093)	0.0275 (0.0083)

Table 2: Accuracy (average and standard desviation) of several methods on the same public database.

	Ac
Proposed method	0.9417 (0.0076)
2^{nd} observer	0.9473 (0.0048)
(Niemeijer et al., 2004)	0.9416 (0.0065)
(Zana and Klein, 2001)	0.9377 (0.0077)
(Jiang and Mojon, 2003)	0.9212 (0.0076)
(Martinez-Perez et al., 1999)	0.9181 (0.0240)
(Chaudhuri et al., 1989)	0.8773 (0.0232)

6 COMPARISON WITH OTHER METHODS

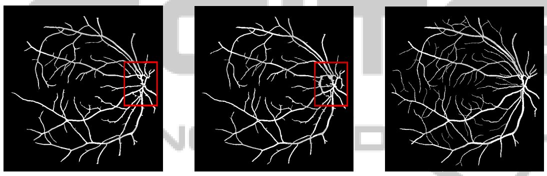
In the literature there are numerous techniques for the extraction of blood vessels, but not too focused on the extraction of retinal vessels. Most edge detection algorithms assess changes between pixels values by calculating image gradient magnitude and then it is thresholded to create a binary edges image (Martinez-Perez et al., 2007; Jiang and Mojon, 2003). Matched filters are filters rotated in different directions in order to identify the cross section of blood vessels (Hoover et al., 2000).Artificial neural networks use a "weight" to determine probability that some input data belonging to a particular output; this system must be adjusted using known output data (Sinthanayothin et al., 1999). Morphological processing exploits vessels characteristics known a priori (line connected segments) and combines morphological operators to achieve the segmentation (Zana and Klein, 2001; Walter and Klein, 2002).

Techniques based on edge detectors lack of strength in distinguishing which are desired edges and which are not, in our case, vessels and optic disc. Matched filters have difficulty adapting to changes in width and orientation of vessels. Techniques focused on neural network are difficult to automate for any image and need a lot of training images. And morphological processing runs the risk of fragmenting the vessels.

7 CONCLUSIONS AND FUTURE WORK

From a fundus image, the implemented system automatically detects blood vessels of a specific region of the image. Moreover, it allows to measure bifurcation angles found and to select branches to know their caliber after a manual intervention, in case it was necessary. These data facilitate expert medical diagnosis and study of the progression of a disease.

The method proposed for the segmentation takes advantage of some of the techniques mentioned in the previous section, besides new contributions, to achieve the correct segmentation and to avoid the disadvantages of using them separately. Specifically, it is based mainly on morphological operators but also used principal curvature information, allowing an enhanced detection of the vessels on to the background of the image. This algorithm has been compared with several methods and, apart from improving the accuracy ratio, it must be stood out that the optic disc edge is not detected as vessel unlike the most edge detection methods. Figure 4 shows our method along with the proposed in (Martinez-Perez et al., 2007). The non-detection of this feature is crucial to avoid multiple errors in the tracking process.



(a) (b) (c)

Figure 4: Segmentation comparison: (a) Proposed method, (b) (Martinez-Perez et al., 2007) method and (c) Manually segmented image belonging to the DRIVE database.

On the other hand, the included measures are accurate and reliable but also dependent on a correct image analysis and rectification of some significant points by the user.

About future work lines, a clinical validation will be carried out to determine the specificity of the system to distinguish between healthy and ill patients. Afterwards, the method will be applied to analyze the retinal microvascular architecture of children with low birthweight and to use it as a prognostic marker of cardiovascular risk.

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