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Bessel Filter Based Blood Vessel Segmentation for Retinal Images

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Abstract:
In the era of digital technology, the blood vessels extraction from the retina becomes a vital source of information for the detection of various diseases related to retinal pathology. The aim of this work is to provide a novel technique to assess patients for diabetes based on four parameters: Sensitivity, Accuracy, Specificity and Area under Curve. These parameters are obtained by performing extraction of blood vessels from a retinal fundus image. Firstly, the outer ring from the input fundus image is removed by using erode morphological operator. Following this process of erosion on input image, this paper applies the concept of Bessel filter for the purpose of enhancement of blood vessels. As a next step, this enhanced blood vessels are extracted by obtaining principal curvature of the image using Hessian matrix and Eigenvalues. Finally, CLAHE operation is applied on the segmented image to improve the contrast of the blood vessels. The outcome of the proposed method is then validated with the pre-segmented retinal image to determine the diabetic retinopathy based on the above mentioned parameters.

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I. INTRODUCTION

The World Health Organization (WHO) has come up with an estimation that by 2030 diabetes would take its stand at seventh place for being the major cause of death across the world. One of the abnormalities faced by the diabetes affected patients is called Diabetic Retinopathy which occurs due to malfunctioning of the retina.

Diabetic Retinopathy generally occurs in patients with the age group between 20 and 60 years. This disease if left untreated might even lead to blindness in patients. Few major factors influencing diabetic retinopathy includes hypertension, blocking of retinal veins. This leads to leakage of fluid into the retinal blood vessels which in turn disrupts the functioning of the eye retina.

It is highly important to monitor the progress of such diseases in patients to avoid complications. The primary constraint in evaluation of retinal images is complexity and noise involved in the images.Computer Aided Diagnosis System has become an indispensable thing for earlier detection and diagnosis of various diseases. This would greatly help for fast decision and objective evaluation. The assessment by CAD system is done on Retinal images which is taken using a high-end fundus camera.

Retinal blood vessels which is spread out across the retina plays a significant role in diagnosing various retinal diseases such as Diabetic Retinopathy, hypertension and choroidal neovascularization. Retinal fundus imaging is one of the computer-aided analysis techniques used in recent years that greatly helps ophthalmologists to diagnose diseases automatically by extracting blood vessels, the optic disc, and macula [1]. Fig (1) depicts the fundus image of a diabetic retinopathy.

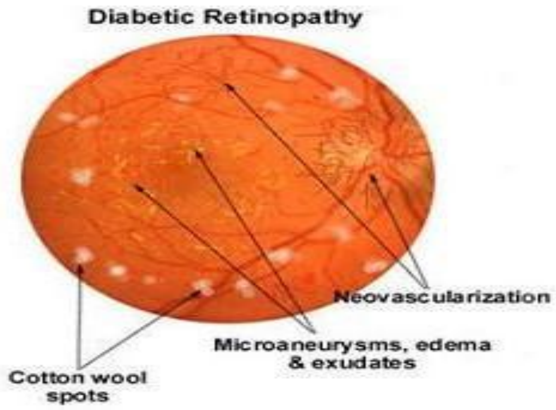

Fig (1): Diabetic Retinopathy fundus image

II. RELATED WORK

Various methods have been proposed for blood vessel segmentation in recent years. The segmentation approach would fall into two major categories – Rule Based Methods and MachineLearning based methods. Rule based segmentation methods basically works on certain set of protocols defined in an algorithmic framework. Machine learning based method, on the other hand, worksupon pre-segmented retinal image (i.e. Ground Truth image) [2]. There are basically two main types that would classify machine learning based methods – Supervised and Unsupervised methods. The major difference between these two methods is that the unsupervised methods make use of heuristics whereas supervised methods works upon various features obtained from the retinal fundus image to extract the blood vessels.

The template matching based unsupervised approach proposes a method to determine the percentage of similarities obtained between the extracted blood vessels and the predefined elongated inverse Gaussian template [3].The supervised learning strategy is generally applied on healthy retinal imageswhich would obtain results with greater accuracy [4]. However,in order to obtain this higher accuracy results, higher level of smoothness needs to be applied on non-vessel region with respect to Laplacian or Gaussian features [5]. The supervised method works on the concept of identification lower frequency structures in the retinal profile image. This defines Gabor features which is typically adopted in the supervised methods [6]. In [7], the pixel representation is computed based on moment invariant features in 7-D vector and the pixel classification is done using neural network [8].

The popular datasets used in retinal segmentation techniques are as follows: (1) Digital Retinal Image for Vessel Extraction (DRIVE), (2) Automated Retinal Image Analyser (ARIA), (3) Structuring Analysis of the Retina (STARE), (4) Diabetes Retina Database (DIARETDB), High Resolution Fundus (HRF) [3].

The major drawback inferred from the existing techniques is that the noise and computational load has not been properly eliminated and the output image contains few uneven illuminations in certain areas. The proposed work provides a novel methodology to extract blood vessels from retinal fundus image that makes use of morphological operators and filter functions which provides accuracy of about 93.75% for diabetic retinopathy patients.

III. PROPOSED METHOD

Fig (2) depicts the process flow of the proposed methodology for the extraction of retinal blood vessels from the fundus image.The first step in the proposed process flowinvolves the process of converting the colour fundus image into a binary image where the pixel value of retinal blood vessels is assigned the value as 1(white) and the pixel value for the remaining background pixels are assigned the value as 0(black). This conversion is carried out based on the threshold value. The pixel values which is marked as 1(white) would have greater luminance than the mentioned threshold.

Further, to remove the outer ring of the retina from the binary image, the morphological operator is applied. Basically, there are two main morphological operators which is widely used in

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image processing – Dilation and Erosion. Dilation typically adds pixels to the object boundaries making it more visible. Whereas Erosion on the other hand, removes the pixels from the object boundaries so that only the substantive objects remain after processing.

In the proposed work, erode morphological operatoris used which takes two inputs as parameters. The first parameter is the input image and second parameter is the structural element based on which the erosion is performed on the input image. The structural element used in this case is 'Line'. And so, erosion is applied on the binary image with the vertical line.

The mathematical definition of erosion on a binary image is as follows:

$$A\theta B = \{z \in E \mid B_z \subseteq A\}, \qquad (1)$$

Where,

A represents a binary image,

B is the structuring element,

E represents a Euclidean space or an integer grid,

B_Z is the translation of B by the vector z, i.e.

$$B_z = \{b + z \mid b \in B\}, \ \forall_z \in E \qquad (2)$$

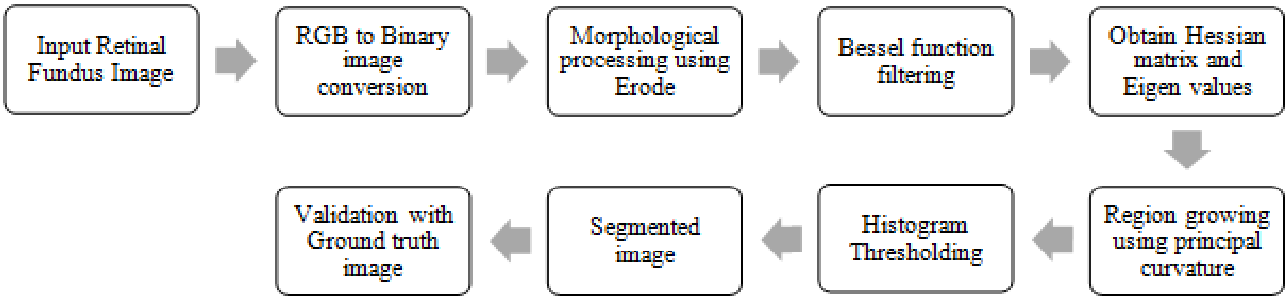

Fig (2): The Process flow of the proposed work

As a next step, Bessel function of the first kind is applied to the image to improve the contrast of the blood vessels [10]. The syntactical representation of the Bessel function is denoted bybesselj (nu, z) where nu – Equation order, z – Functional domain.

The representation for the Bessel function of first kind is as follows:

$$B(x,y) = \left[\frac{C_n\sqrt{n_1^2 + n_2^2}}{N}\right] e^{j(2\pi/N)(x)} \qquad (3)$$

Where,

$x = n_1 \cos\theta - n_2 \sin\theta$

$N = \sqrt{2n^2}$ whereas, $-n < n_1 < n$

$-n < n_2 < n$

The below mathematical representation defines the Bessel's equation and the solution of which is established as Bessel functions.

$$z^2 \frac{d^2y}{dz^2} + z\frac{dy}{dz} + (z^2 - \upsilon^2)y = 0 \qquad (4)$$

where υ is a real constant.For a non-integer υ, the Bessel function is defined by,

$$J_\upsilon(z) = \left(\frac{z}{2}\right)^\upsilon \sum_{(k=0)}^{\infty} \frac{\left(\frac{-z^2}{4}\right)^k}{k!\,\Gamma(\upsilon + k + 1)} \qquad (5)$$

When the index υ is an integer, the Bessel functions of the first kind is governed by formula,

$$J_{-\upsilon}(z) = (-1)^\upsilon J_\upsilon(z) \qquad (6)$$

The calculation of the Bessel function of the first kind J_υ is performed using the formula J = besselj(nu, Z) where, Z represents an array and this computation is done for each element of the array Z. In the above equation, nuis real but it doesn't need to be an integer. The output of the above equation is also real provided Z is positive.

The output size is determined based on the size of the parameter's nu and Z. If both the parameters nu and Z are of the same size, the output value also holds the size of the same. If

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either of the input parameter is a scalar, then that parameter would be expanded to size of the other input parameter . The result of the above equation would be a 2-D table if one of its input parameter is a row vector and the other parameter is a column vector.

The Bessel function of third kind which is related to Hankel functions is defined as shown below.

$$H_{\upsilon}^{(1)}(z) = J_{(\upsilon)}(z) + iY_{\upsilon}(z) \quad (7)$$

$$H_{\upsilon}^{(2)}(z) = J_{(\upsilon)}(z) - iY_{\upsilon}(z) \quad (8)$$

Where, $H_{\upsilon}^{(k)}(z)$ is besselh, $J_{\upsilon}(z)$ is besselj and $Y_{\upsilon}(z)$ is bessely.

As a result, after applying morphological operator and Bessel function filter, the blood vessels are enhanced and the other retinal structures are removed from the image.

The next step in the work flow involves the process of obtaining the principal curvature from the filtered image. The main purpose of obtaining this principal curvature is to identify a specific region in an image. This region detectors could be broadly classified as shown below,

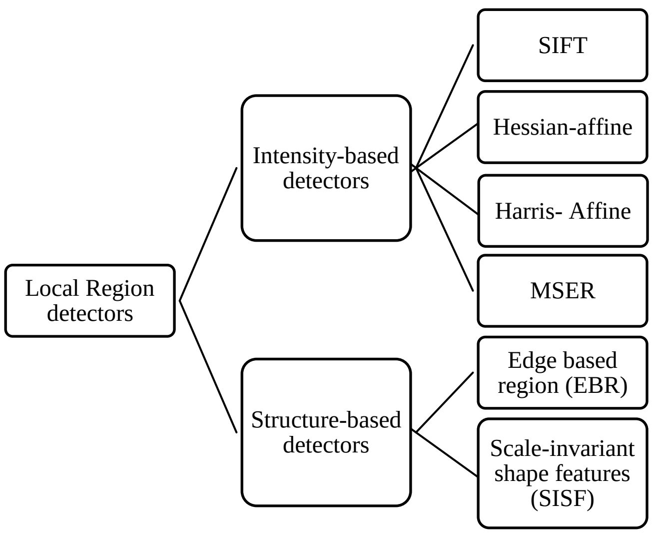

Fig (3): Local Region detectors

- Intensity detectors works based on analysing intensity patterns to identify the region that satisfies certain criteria.
- Structure detectors works based on the structure of the image such as line, curve, edges etc. to identify specific region.

In our proposed work, the structure-based detectors is used. This makes use of a curvilinear structure called ridges to obtain a clear structure of an image. To obtain this curvilinear images, Hessian matrix is calculated. In general, the Hessian matrix provides geometric information about the image.

Hessian matrix is basically a square matrix which is represented using second order partial differential equation,

$$H = \begin{bmatrix} I_{xx} & I_{xy} \\ I_{yx} & I_{yy} \end{bmatrix} \quad (9)$$

In the above equation, $I_{xy} = I_{yx}$ which implicitly explains that Hessian matrix is symmetric in nature.

In order to calculate Hessian matrix, we need to compute the second order derivative in each direction as shown below,

[gx, gy] = gradient (double (Image));
[gxx, gxy] = gradient (gx);
[gyx, gyy] = gradient (gy);

Thus the coefficients of Hessian matrix for every pixel is given as [gxx, gxy; gyx, gyy] where gxy=gyx.

Furthermore, its Eigen values and Eigen vectors are obtained to provide more information about the matrix. Ideally, we employ Eigen values to design a filter for vessel enhancement in digital medical image. Since the Hessian matrix are symmetric by nature, all its Eigen values would be real numbers. The Eigen values of Hessian matrix H are typically called as the principal curvatures and are invariant under rotation.

The Eigen values are calculated as shown below,

$$\left\{ \begin{array}{l} \left\{ \frac{1}{2}\left(I_{xx} + I_{yy} - \sqrt{I_{xx}^2 + 4I_{xy}^2 - 2I_{xx}I_{yy} + I_{yy}^2} \right), 0 \right\}, \\ \left\{ 0, \frac{1}{2}\left(I_{xx} + I_{yy} + \sqrt{I_{xx}^2 + 4I_{xy}^2 - 2I_{xx}I_{yy} + I_{yy}^2} \right) \right\} \end{array} \right\}$$

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Then the Hessian matrix is rotated in such a way that the maximal and minimal curvatures are obtained. The syntax to find eigenvalues is eig (A) where A is the matrix. From the result, the maximum Eigen value is taken and multiplied with the matrix of the eroded image obtained after applying erode operator. This would return the maximum principal curvature of the image. In order to determine the directions of the principal curvature, Eigen vectors of the Hessian matrix is used.

Then, the blood vessel segmentation is performed based on thresholding technique. All the pixels with Intensity beyond the mentioned threshold value is marked as "Vessel pixels". Whereas, the pixels which has intensity lower than the threshold value is labelled as "background pixels".

In the next step, the segmented image is enhanced to improve the contrast of the blood vessels. Contrast-Limited Adaptive Histogram Equalization (CLAHE) is used to serve this purpose.

CLAHE operates on small regions which is referred to as 'Tiles', rather than on the entire image.

The main objective of using this technique is to minimize the noise load present in the image by limiting the contrast in homogeneous areas. CLAHE takes three inputs as parameters – Intensity image I, NumTiles, nBins.

- Intensity image I is the image upon which the histogram equalization is applied.
- NumTiles defines the number of tile rows and columns in the format [M N]. Here, both M and N are positive integers whose minimum value should be atleast 2. The default value of [M N] is set to [8 8].
- nBins is a positive integer which defines a number of bins to be set for the histogram. This is typically used to build a contrast enhancement transformation. The default value is set to 256. Higher the value, greater the dynamic range which in turn would result in lowering the processing speed.

This technique applies contrast enhancement to each tiles and then the neighbouring tiles are combined using bilinear interpolation.

Bilinear interpolation is the process used to eliminate the artificially induced boundaries. This ideally means applying a linear interpolation in two direction. This process uses 4 nearest neighbour and takes the average of it to determine the output.

For example, consider a 2×2 image which is up scaled to 4×4 image as shown below,

10	20
30	40

$\xrightarrow{2x}$

P1	P2		

Fig (4): 2×2 matrix up scaled to 4×4

To assign a value to pixel P1, we need to determine its neighbour pixels in the input 2×2 image. We assume that each pixel is represented by its centre value. Let's consider that the first pixel starts with the value of 0.5 and next at 1.5 and so on. Each pixel in the given 2×2 image is of unit length and width. Refer Fig (5) for the pixel representation.

P1	P2

0.5 1 1.5 2 2.5

Fig (5): Pixel representation

So, the location of each pixel in the given input image is {'10':(0.5,0.5), '20':(1.5,0.5), '30':(0.5,1.5), '40':(1.5,1.5)}.

The next step would be to find the coordinates of each unknown pixel. For example, the coordinate of P1 in the given input image is (0.25, 0.25), for P2, it is (0.75, 0.25) and so on.

Then these coordinates of each unknown pixel is then compared with the input image pixels to

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determine the nearest pixel. For example, P1 (0.25, 0.25) is nearest to 10(0.5, 0.5) and so P1 is assigned the value of 10. Hence the final result would be as shown below.

10	20
30	40

2x →

10	10	20	20
10	10	20	20
30	30	40	40
30	30	40	40

Fig (6): Resultant matrix

Finally, the smaller segments from the binary image is removed by performing the operation of area opening. This operation takes two input parameters – binary image BW and the pixel P. Any connected component that has the pixels less than the mentioned pixel P would be removed from the image.

The resultant binary image obtained after performing area opening operation is compared with the pre-segmented image (ground truth) to determine the various metrics required to detect diabetic retinopathy.

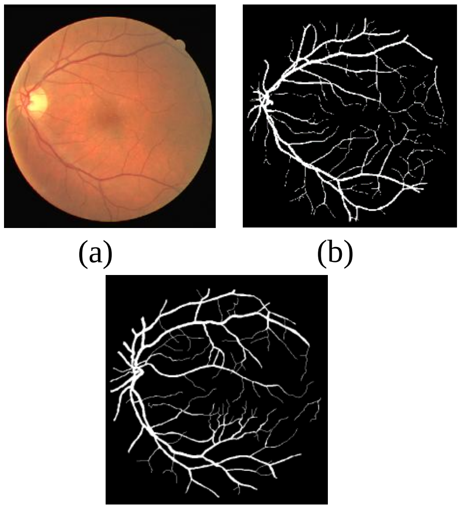
IV. RESULTS AND DISCUSSIONS

A. Dataset

For the testing of the proposed method, high resolution fundus images are captured. There are around 20 pre-segmented (ground truth) fundus images. All the images are of 565×584 pixels in size. Firstly, the blood vessels are segmented and these segmented images are then compared with the 20 pre-segmented (ground truth) image to obtain the performance evaluation metrics.

B. EXPERIMENTAL RESULTS

Fig (7) shows the final outcome of the proposed algorithm.



(a) (b)

(c)

Fig (7): Outcome of the proposed algorithm a) Original Image b) Ground Truth Image c) Segmented Image

The retinal blood vessel segmentation algorithm is evaluated based on the following metrics – True Positive (TP), False Positive (FP), True Negative (TN), Specificity (SPE), Accuracy (ACC), Sensitivity (SEN), and Area under Curve (AUC).

- A pixel is referred to as True Positive (TP)if it is distinguished as a vessel in both the segmented and ground truth image.
- A pixel is referred to as False Positive (FP)if it is distinguished as a vessel in segmented image and noted as a background in ground truth image.
- A pixel is referred to as True Negative (TN)if it is distinguished as a background in both segmented and ground truth image.

The metrics are calculated as shown below,

$$\text{Specificity (SPE)} = \frac{TN}{TN+FP}$$

$$\text{Accuracy (ACC)} = \frac{(TP+TN)}{(TP+TN+FP+FN)}$$

$$\text{Sensitivity (SEN)} = \frac{TP}{TP+FN}$$

$$\text{Area under Curve (AUC)} = \frac{(SPE+SEN)}{2}$$

The following TABLE 1 illustratesthe comparison of the proposed work with the existing approach with respect to its performance.

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TABLE 1. PERFORMANCE COMPARISON TABLE FOR THE PROPOSED WORK WITH EXISTING APPROACH

Method	Sensitivity (%)	Specificity (%)	Accuracy (%)	Area under curve (%)
Christodoulidis et al [9]	98.52	94.79	85.06	79.42
JasemAlmotiri[3]	98.16	95.27	74.06	79.55
Ozkaya1 U[5]	97.80	94.90	73.90	75.89
Ling Luo[7]	95.79	94.30	71.52	75.04
Azzoapardi [10]	97.04	94.42	76.55	74.73
Viraktamath[4]	97.50	94.30	74.10	82.20
Diego Marina[8]	97.82	94.66	73.32	79.19
Proposed Method	87.71	99.33	95.83	87.79

As mentioned above, the proposed algorithm has attained an acceptable percentage of Sensitivity, Specificity, Accuracy and Area under curve.

Furthermore, the below TABLE 2 illustrates the performance evaluation of the proposed work on the 20 test datasets.

TABLE 2. PERFORMANCE EVALUATION TABLE FOR THE PROPOSED WORK

Test No	Sensitivity (%)	Specificity (%)	Accuracy (%)	Area under curve (%)
01	80.22	98.63	95.76	79.42
02	80.65	98.45	95.04	79.55
03	73.51	98.26	95.32	75.89
04	70.76	99.33	93.70	75.04
05	70.84	98.62	94.03	74.73
06	74.22	90.18	88.85	82.20
07	80.08	98.30	94.93	79.19
08	83.96	97.89	94.57	80.92
09	75.61	93.16	91.69	84.39
10	79.77	98.48	95.44	79.13

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11	84.39	97.84	95.83	81.12
12	75.78	99.22	95.67	77.50
13	82.12	98.80	95.83	80.46
14	76.78	86.61	85.65	81.70
15	81.24	92.97	91.95	87.10
16	86.60	97.88	94.48	82.24
17	79.13	91.60	90.51	85.37
18	84.68	98.42	95.50	81.55
19	87.71	97.84	95.25	82.78
20	79.36	96.21	94.94	87.79
Average	79.37	96.43	93.75	80.90
Maximum	87.71	99.33	95.83	87.79
Minimum	70.76	91.60	90.51	74.73

The result obtained shows that the average accuracy achieved through the proposed work is 93.75%.

V. CONCLUSION AND FUTURE WORK

In the proposed algorithm, the blood vessels are segmented from the retinal image based on the morphological operation and thresholding. This extracted blood vessels plays a major role in identifying various retinal diseases including diabetic retinopathy. The implemented algorithm is tested using DRIVE dataset with consists of 20 pre-segmented images in the database. The segmented image obtained using the proposed algorithm is compared with these pre-segmented images to evaluate the performance metrics. The average metrics achieved through this proposed algorithm is 96.43% Specificity, 93.75% Accuracy, 79.37% Sensitivity, and 80.90% Area under Curve. As mentioned, the proposed algorithm has obtained acceptance result in terms of accuracy.

In future, this algorithm could be modified to increase the performance and extend the utilization of this work in diagnosing various other diseases like hypertension, glaucoma.

VI. REFERENCES

[1] K V Maya, K S Adarsh, "Detection of Retinal Lesions Based on Deep Learning for Diabetic Retinopathy", 2019 Fifth International Conference on Electrical Energy Systems (ICEES).

[2] S. Chaudhuri, S. Chatterjee, N. Katz, M. Nelson, and M. Goldbaum, “Detection of blood vessels in retinal images using two-dimensional matched filters,” IEEE Transactions on Medical Imaging, vol. 8, no. 3, pp. 263–269, 1989. View at Publisher · View at Google Scholar · View at Scopus.

[3] JasemAlmotiri 1,*, KhaledElleithy 1 and AbdelrahmanElleithy 2, "Retinal Vessels Segmentation Techniques and Algorithms: A Survey”.

[4] Dr.S.V.Viraktamath, Miss.VasantaKoti, Miss. SumanRagi, Miss. NamitaPai, “Blood Vessels Extraction of Retinal Image Using Morphological Operations”.

[5] U. Ozkaya1 *, Ş. Ozturk2 , , B. Akdemir1 and L. Seyfi1, “An Efficient Retinal Blood Vessel Segmentation using Morphological Operations”.

[6] Aswini S, Suresh A ,Priya S ,Santhosh Krishna B V,”Retinal Vessel Segmentation Using Morphological Top Hat Approach On Diabetic Retinopathy Images”.

[7] Ling Luo1, Dali Chen1, Dingyu Xue1, “Retinal Blood Vessels Semantic Segmentation Method Based on Modified U-Net”.

[8] Diego Marina, Arturo Aquino*, Manuel Emilio Gegundez-Arias and Jose Manuel Bravo, “A New Supervised Method for Blood Vessel Segmentation in Retinal Images by Using Gray-Level and Moment Invariants-Based Features.

[9] Christodoulidis, A., et al.: A Multi-scale Tensor Voting Approach for Small Retinal Vessel Segmentation in High Resolution Fundus Images , Computerized Medical Imaging and Graphics (2016) Volume 52, September 2016, Pages 28-43.

[10] Azzopardi,G.,Strisciuglio,N.,Vento,M.,Perkov.:Trainable COSFIRE filters for vessel delination with application to retinal images.Medical Image Analysis,Vol 19 (2015) 46-57