Retinal Blood Vessels Extraction using Matched Filter on High Resolution Fundus Image Database

Deepali D. Rathod
Dept of CS and IT,Dr. Babasaheb Ambedkar Marathwada University, Aurangabad MS (India)

Ramesh R. Manza
Dept of CS and IT,Dr. Babasaheb Ambedkar Marathwada University, Aurangabad MS (India)

Yogesh M. Rajput
Dept of CS and IT,Dr. Babasaheb Ambedkar Marathwada University, Aurangabad MS (India)

ABSTRACT
In this paper we have extracted the retinal blood vessels using 2D Matched filter. The proposed algorithm is consisting of some preprocessing steps on RGB image like extraction of green channel; contrast limited adaptive histogram equalization, and morphological opening operation. After extraction of retinal blood vessels using matched filter, we have calculated fractal dimension for finding the architectural distortion. Accuracy is calculated using person correlation coefficient, and achieved 98.3 % accuracy. Operations are done on the 45 images of HRF database.15 images are of Healthy, 15 images are of Diabetic retinopathy, and 15 are of Glaucoma.

Keywords
Diabetic Retinopathy, Retinal blood vessels, Matched Filter, HRF database

1. INTRODUCTION
Diabetic retinopathy is one type of condition in which increased blood sugar level causes swelling in the retinal blood vessels, and blood is get leaked in to the retina. We can say that it is effect of diabetes on the eye. DR affects up to 80% of diabetics around the world and it is one of the leading causes of blindness in the U.S. In western world it is the second greatest cause of blindness [1].According to the world health organization report, around 31.7 million people are suffering from diabetes and in 2030 it may be 79.4 million[2]. Over all 210 million people have diabetes mellitus all over the world. Out of that 10-18 % would have had or develop DR. For that there is need to early detection of diabetic retinopathy. With this research we can prevent the people from the vision loss [3].Extraction of retinal blood vessels is very important for detection of diabetic retinopathy, hypertension, glaucoma, arteriosclerosis and occlusion of retinal artery, etc. [4]. It is tree-like geometry [5].For extraction of retinal blood vessels we have proposed algorithm using matched filter. In preprocessing step we have converted RGB image to green channel. Then Contrast-limited adaptive histogram equalization is used for enhancing the image quality. Then matched filter is created, and by using this matched filter we have extracted retinal blood vessels. When extraction of retinal blood vessels is done we have applied skeletonization on the extracted output. Then we have calculated Fractal Dimension of non-skeletonized vascular tree and skeletonized vascular tree image, we have also skeletonized gold standard images from the HRF database and calculated their Fractal Dimension. After calculation of fractal dimension of all images we have applied statistical methods that are we have calculated the mean, variance, and standard deviation. We have calculated the accuracy using pearson correlation coefficient. It is measure of strength of a linear association between two variables.

2. RELATED WORK
Bob Zhang et al have done the experiment on Retinal vessel extraction by matched filter with first-order derivative of Gaussian. They used databases as STARE and DRIVE for this work. In this paper they propose a novel extension of the MF approach, i.e. MF-FDOG, to detect retinal blood vessels. They got Vessel extraction accuracy results on the STARE database is 0.9484 and on DRIVE database 0.9382 [6].

Jan Odstrcilik et al works on they improve the concept of matched filtering, and propose a novel and method for segmenting retinal vessels. They have varying vessel diameters in high-resolution color fundus images. They provide a new publicly available high-resolution fundus image database of healthy and pathological retinas. There algorithm achieves accuracy of 95% evaluated on the new database [7].

Nidhal Khdhair El Abbadi and Enas Hamood Al Saadi, work on the segmentation of retinal blood vessels using mathematical morphology. They present an automated approach for blood vessels extraction using mathematical morphology. They have used the techniques like enhancement operation is applied to the original retinal image in order to remove the noise and increase contrast of retinal blood vessels and morphology operations are employed to extract retinal blood vessels. This operation of segmentation is applied to binary image of top hat transformation. The result was compared with other algorithms and it gives better result that is 8.1501 [8].

Yogesh M.Rajput et al represent the fresh algorithm for the detection and measurement of blood vessels of the retina, which is general enough that it can be applied to high resolution fundus photographs. Firstly, pre processing operations done on fundus images, then simple vessel segmentation technique has been describe, formulated in the language of 2D Median Filter that is used for retinal vessel detection, for performing this function used database from Dr. Saswade. The segmentation achieves a true positive rate of 100%, false positive rate of 0%, and accuracy score of 1. In this algorithm, the classification is done through the diameter of the retinal vessels, like 25 mm is the standard value for the normal blood vessel, if below the range of 25 mm, the new blood vessels are nourishing the retina and if above range of 25 mm, the blood vessels get swell or rupture [9].

Nazneen Akhter et al have done the work using fractal dimension. They have used DRIVE database for the work. Fractal dimension of retina images for diabetic subjects show higher fractal dimensions indicating higher degree of structural complexity associated with the image whereas images of healthy subjects show a lower value of fractal dimension indicating limited complexity of structure. It is shown that fractal dimension can be used to distinguish diabetic subjects from healthy subjects and hence this technique could be used in diagnosis of diabetes using images of retina. It is interesting that during other diagnostic procedures related to retina images, this information can be generated as additional information adding value to the diagnostic procedures. Details of implementation of the technique are presented [10].

Stefan Talu, Stefano Giovanzana , studied the geometric complexity of the human retinal vascular network by using fractal dimension,They have calculated fractal dimension using box counting method. They calculate mean and got 1. 6147 ± 0.0151 for normal vascular network for and for skeletonized 1.5554 ± 0.0239. Also, the mean lacunarity parameter was 0.5210 ± 0.0343 in segmented version and 0.2916 ± 0.0218 in skeletonised version [11].

3. DATABASE

For this work we have use High Resolution Fundus (HRF) Image database. This database is publically available on http://www5.cs.fau.de/research/data/fundus-images/. There are totally 45 images in this database.15 images are of Healthy patients, 15 images are of glaucomatous patients, and 15 are of Diabetic retinopathy patients. The database is provided by the Pattern Recognition Lab (CS5), the Department of Ophthalmology, Friedrich-Alexander University Erlangen-Nuremberg (Germany), and the Brno University of Technology, Faculty of Electrical Engineering and Communication, Department of Biomedical Engineering, Brno (Czech Republic).

4. WORK FLOW

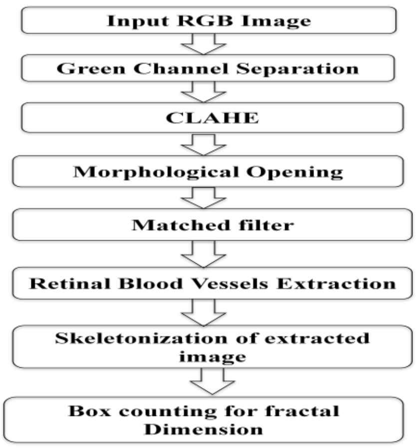

Fig 1: Work Flow for retinal blood vessel extraction using Mathched Filter

5. METHODOLOGY

5.1. RGB Image

Images use from the HRF database is of RGB type. RGB images sometimes referred as a true color image [12]. In our experiments we have work on the Green channel images. We are using green channel images because the intensity of green channel image is more than the red and blue channel [13].

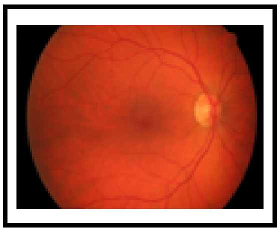

Fig 2: RGB image from HRF database

5.2. Green Channel Extraction

All the work is done on the Green channel images. We have use only green channel images from the RGB because intensity of green channel is more as compare to red and blue [13].

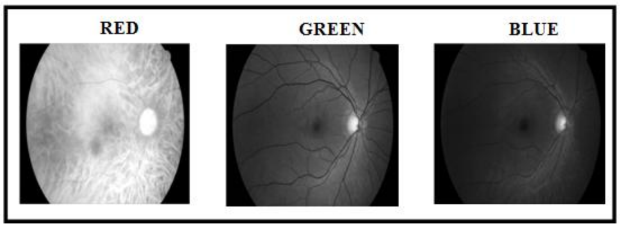

Fig 3: Red Channel, Green Channel, Blue Channel

The above figure shows the red channel, green channel, Blue channel separately. From this figure we can say that the intensity of red and blue is low. And intensity of green channel is high. Hence for all the work done is using green channel images.

5.3. Contrast Limited Adaptive Histogram Equalization (CLAHE)

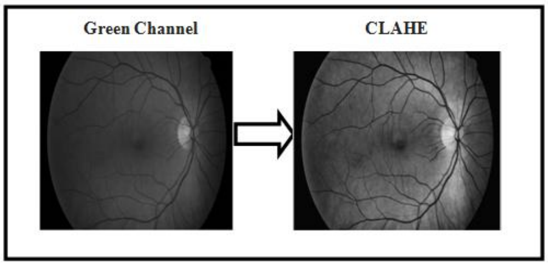

Fig 4: Green channel to CLAHE

After green channel extraction, applied contrast limited adaptive histogram equalization on green channel image. Contrast limited adaptive histogram equalization is given as follows:

$$g = [g_{max} - g_{min}] * P(f) + g_{min} \qquad (1)$$

Where g_{max} = Maximum pixel value

g_{min} = Minimum pixel value

g = computed pixel value

$P(f)$= CPD (Cumulative probability distribution)

By using this contrast limited adaptive histogram equalization function we have enhance the quality of image. The CLAHE algorithm partitions the images into contextual regions and applies the histogram equalization to each one. This evens out the distribution of used grey values and thus makes hidden features of the image more visible [13].

5.4. Morphological Open Operation

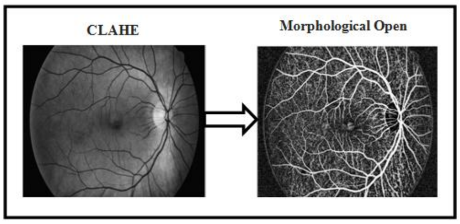

Fig 5: Morphological Open Operations

On the contrast limited adaptive histogram equalization output we have perform morphological opening. Morphological opening can be described as an erosion operation followed by a dilation operation [14].

$$A \; o \; B = (A \,\theta\, \mathrm{B}) \oplus B \qquad (2)$$

Where θ and ⊕ denote erosion and dilation, respectively [14].

5.5. Matched Filter

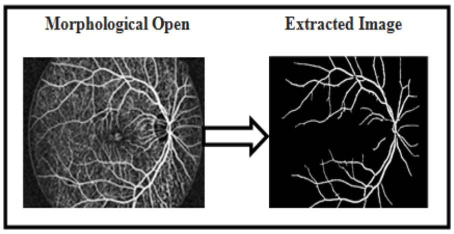

Fig 6: Matched filter for retinal vessel extraction

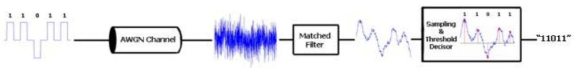

Fig 7: Matched filter System

After the open morphological operation we have apply the 2D Matched filter. We have created 12 Matched filters. After applying the matched filter we got the extracted retinal blood vessels. Mathematically Matched filter is define as follows

$$M_{filter\,ed}(t) = M(t) * h(t) \qquad (3)$$

Where * is the convolution

$$M(t) = \sum_{k=-\infty}^{\infty} a_k * \pi\left(\frac{t-kT}{T}\right) \qquad (4)$$

$$h(t) = \pi\left(\frac{t}{T}\right) \qquad (5)$$

$$a_k = \begin{cases} 1\,, if\ bit\ k\ is\ 1, \\ 0,\ if\ bit\ k\ is\ 0. \end{cases} \qquad (6)$$

6. RESULTS

6.1. Healthy

T is the time length of one bit, a_k is the scaling factor, h (t) is time-reversed complex-conjugated scaled version of the signal [15].Where ○ denotes the opening operation.

5.6. Skeletonization

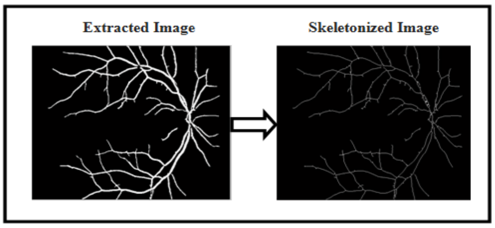

Fig 8: Skeletonization of retinal vessel extraction

We have extracted the retinal blood vessels using Matched filter, after that we have applied skeletonization function on the extracted image and calculated the Fractal Dimension of non-skeletonized vascular tree, skeletonized vascular tree. The mathematical formula for skeletonization is

$$S(A) = \bigcup_{K=0}^{K} S_{k(A)} \qquad (7)$$

Where

$$S_k(A) = (A \,\theta\, \mathrm{kB}) - (\mathrm{A} \,\theta\, \mathrm{kB})\mathrm{o}\ \mathrm{B} \qquad (8)$$

B is the structuring element and $(A \,\theta\, \mathrm{kB})$ indicates k successive erosions of A.

$$(A \,\theta\, \mathrm{kB}) = (\ldots((\mathrm{A} \,\theta\, \mathrm{B})\theta \ldots)\theta\mathrm{B} \qquad (9)$$

k is the last iterative step before A erodes to an empty set, in other words.

$$K = \max\{k | (A \,\theta\, kB) \neq \emptyset\} \qquad (10)$$

Hence we can obtain the skeletonization S (A) by taking union of skeleton subsets Sk (A)

5.7. Fractal Dimension

After the extraction of retinal blood vessels using matched filter algorithm we have calculated fractal dimension of the retinal blood vessels Mathematical equation for the Box counting for calculation of fractal dimension is [16]

$$D = \left(\frac{\log(N)}{\log(r)}\right) \qquad (11)$$

Where D is the fractal d (30) N is the number of boxes that covers the pattern

Table 1: Fractal dimension for Healthy images

Sr. No.	Image Name	Fractal Dimension of non-skeletonized vascular tree	Fractal Dimension Using Gold Standard	Fractal Dimension of skeletonized vascular tree	Fractal Dimension using skeletonization of gold standard
1	01_h	1.6606	1.6705	1.4942	1.3803
2	02_h	1.6807	1.6667	1.5137	1.3659
3	03_h	1.6500	1.6748	1.4836	1.3701
4	04_h	1.6578	1.6610	1.4893	1.3612
5	05_h	1.5967	1.6556	1.4016	1.3564
6	06_h	1.6554	1.6699	1.4829	1.3811
7	07_h	1.6143	1.6540	1.4337	1.3570
8	08_h	1.6409	1.6687	1.4618	1.3704
9	09_h	1.6139	1.6374	1.4453	1.3582
10	10_h	1.6315	1.6500	1.4600	1.3733
11	11_h	1.6358	1.6599	1.4636	1.3704
12	12_h	1.6641	1.6740	1.4878	1.3769
13	13_h	1.6462	1.6511	1.4710	1.3611
14	14_h	1.6454	1.6515	1.4608	1.3777
15	15_h	1.6121	1.6383	1.4310	1.3676
Mean		1.64036	1.65889	1.46535	1.36851
Standard Deviation		0.02309	0.012	0.02883	0.00839
Variance		0.00053	0.00014	0.00083	0.00007

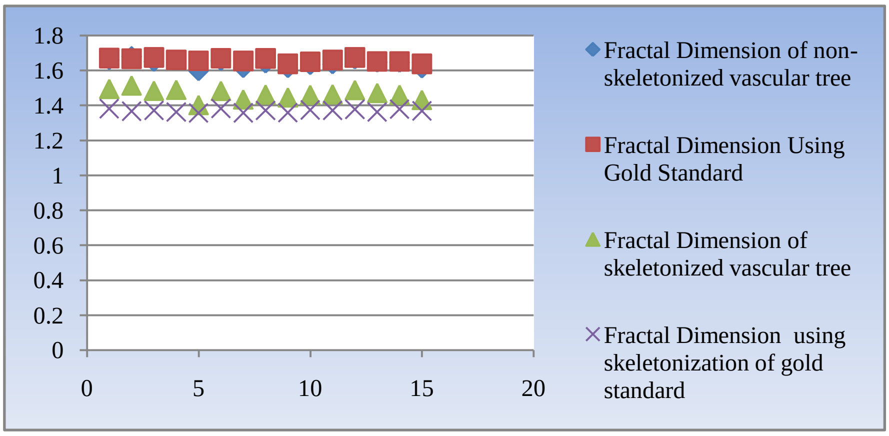

Fig 9: Graph of Fractal dimension for Healthy images

6.2. Diabetic Retinopathy

Table 2: Fractal dimension for Diabetic Retinopathy images

Sr.no.	Image Name	Fractal Dimension of non-skeletonized vascular tree	Fractal Dimension Using Gold Standard	Fractal Dimension of skeletonized vascular tree	Fractal Dimension using skeletonization of gold standard
1	01_dr	1.6154	1.5854	1.4399	1.3416
2	02_dr	1.6339	1.6131	1.4695	1.3401
3	03_dr	1.6690	1.6064	1.4937	1.3611
4	04_dr	1.6296	1.5982	1.4486	1.3924
5	05_dr	1.6257	1.6100	1.4467	1.3704
6	06_dr	1.6468	1.6338	1.4911	1.3717
7	07_dr	1.6530	1.6374	1.4684	1.3555
8	08_dr	1.6971	1.6333	1.5173	1.3819
9	09_dr	1.5872	1.6205	1.4119	1.3853
10	10_dr	1.6174	1.6516	1.4236	1.3736
11	11_dr	1.6307	1.6478	1.4520	1.3616
12	12_dr	1.6229	1.6210	1.4488	1.3824
13	13_dr	1.6157	1.6216	1.4380	1.3487
14	14_dr	1.6870	1.6351	1.5222	1.3416
15	15_dr	1.6754	1.6161	1.5049	1.3401
Mean		1.64045	1.62209	1.46511	1.3632
Standard Deviation		0.03047	0.01818	0.03387	0.01806
Variance		0.00093	0.00033	0.00115	0.00033

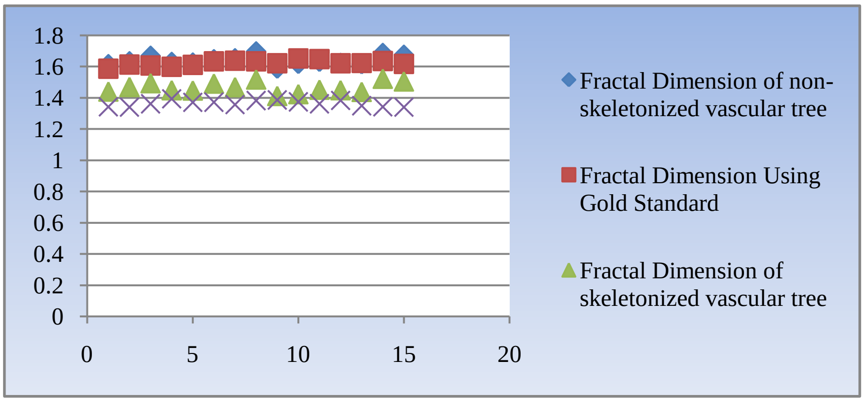

Fig 10: Graph of Fractal dimension for Diabetic Retinopathy images

6.3. Glaucoma

Table 3: Fractal dimension for Glaucoma images

Sr.no.	Image Name	Fractal Dimension of non-skeletonized vascular tree	Fractal Dimension Using Gold Standard	Fractal Dimension of skeletonized vascular tree	Fractal Dimension using skeletonization of gold standard
1	01_g	1.6060	1.6190	1.4262	1.3732
2	02_g	1.6253	1.6321	1.4468	1.3824
3	03_g	1.5209	1.6009	1.3358	1.3468
4	04_g	1.5704	1.6142	1.3869	1.3575
5	05_g	1.5766	1.6161	1.3789	1.3547
6	06_g	1.5986	1.6216	1.4038	1.3606
7	07_g	1.6237	1.6156	1.4494	1.3687
8	08_g	1.6600	1.6207	1.4883	1.3761
9	09_g	1.6061	1.6177	1.4315	1.3723
10	10_g	1.6433	1.6165	1.4842	1.3704
11	11_g	1.6096	1.6353	1.4290	1.3807
12	12_g	1.6466	1.6448	1.4664	1.3928
13	13_g	1.6118	1.6210	1.4427	1.3755
14	14_g	1.6163	1.6256	1.4421	1.3758
15	15_g	1.6068	1.6300	1.4243	1.3732
Mean		1.60877	1.62207	1.42909	1.37071
Standard Deviation		0.03403	0.01041	0.04026	0.01173
Variance		0.00116	0.00011	0.00162	0.00014

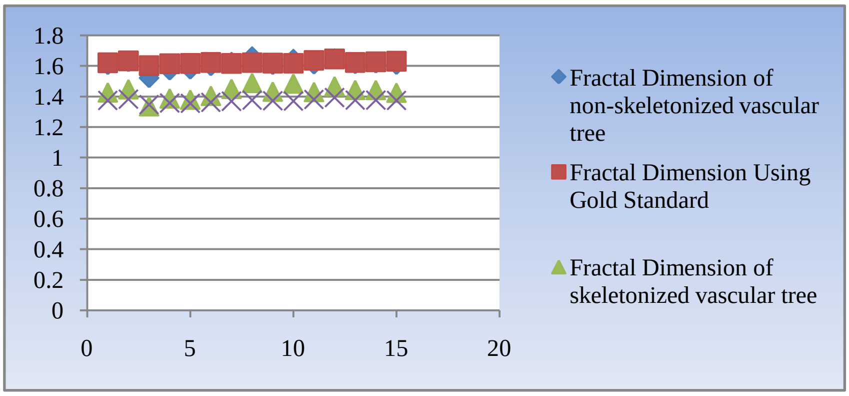

Fig 11: Graph of Fractal dimension for Glaucoma images

We have calculated the accuracy using pearson correlation coefficient. It is measure of strength of a linear association between two variables [17].

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2[n\sum Y^2 - (\sum Y)^2}} \qquad (12)$$

For that we have calculated the fractal dimension of non-skeletonized and skeletonized vascular tree and this fractal dimensions were correlated. And we got the following result

Table 4: Pearson Correlation Coefficient

Database	**Pearson correlation coefficient**	**Result in Percentage**
Healthy	0.97929720	98%
Diabetic Retinopathy	0.99461318	99%
Glaucoma	0.96996674	98%

7. CONCLUSION

In this work we have successfully extract the retinal blood vessels using matched filter. We have done skeletonization of extracted image and compare the output using Fractal dimension. We have applied statistical techniques Mean, standard deviation and Variance of fractal dimension. We have achieved 98.3 % accuracy for retinal blood extraction using Matched filter using Pearson correlation coefficient.

8. ACKNOWLEDGEMENT

We have used the database which is provided by the Pattern Recognition Lab (CS5), the Department of Ophthalmology, Friedrich-Alexander University Erlangen-Nuremberg (Germany), and the Brno University of Technology, Faculty of Electrical Engineering and Communication, Department of Biomedical Engineering, Brno (Czech Republic). And we are thankful to University Grant Commission (UGC) for providing us a financial support for the Major Research Project entitled "Development of Color Image Segmentation and Filtering Techniques for Early Detection of Diabetic Retinopathy" F. No.: 41 – 651/2012 (SR) also we are thankful to DST for providing us a financial support for the major research project entitled "Development of multi resolution analysis techniques for early detection of non-proliferative diabetic retinopathy without using angiography" F.No. SERB/F/2294/2013-14.

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