

Retinal Vessel Segmentation using Combined Fuzzy and Gabor Filter

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Abstract

Fundus image plays an important role in diagnosis of eye diseases but digital images are often contaminated by impulse noise. We present a method for automatic retinal segmentation from highly noisy fundus images using combined Fuzzy and Gabor Filter. The approach uses Fuzzy filter to remove noise from the fundus image. Then Multiscale Gabor filter bank is used to obtain the segmented image. The proposed technique is tested using publicly available DRIVE database and obtains an average value of sensitivity, accuracy and Matthews correlation coefficient of 77.83%, 94.66% and 68.37 respectively. The results obtained are compared with existing technique that makes use of only Gabor filter bank.

Keywords

Fuzzy Filter, Gabor Filter, Fundus Image, Vessel Segmentation

I. Introduction

Fundus image assessment plays an important role in diagnoses of eye diseases such as diabetic retinopathy, Glaucoma, age-related macular degeneration. From fundus image retinal vessels need to be segmented to compute measures like vessel area and length, vessel width, abnormal branching, and also to provide a localization of vascular structures [1]. But when the number of vessels in an image is large, or when a large number of images are acquired, manual delineation of the vessels becomes tedious or even impossible [2]. Hence automatic segmentation of retinal vessels is needed.

Numerous methods have been proposed for vessel segmentation. The paper [3] states the use of 2-D matched filter for vessel segmentation. This method is improved in [4] using matched filter with first order derivative of Gaussian filter. In [5] multi-wavelet kernels and multi-scale hierarchical decomposition are used. In [6] 2-D Gabor wavelet is used for segment vessel network. The use of bit plane and centerline detection to localize retinal vessel from fundus image is introduced in [7]. The use of Adaboost to segment fundus image is presented in [8]. Methods like line operators [9], Contourlet transform [10], Divergence of field vector [11], local adaptive histogram equalization [12] and multiscale line detection [13] are also used to segment the fundus image.

But the issue of noise is ignored in majority of existing literature. To solve this problem, combined Fuzzy and Gabor filter based segmentation is used to segment the highly noisy and corrupted images. Drive database is used to evaluate segmentation results. In this paper, firstly proposed algorithm is explained followed by results and discussions section. Last section summarizes the conclusion.

II. Proposed Method

In this method combined Fuzzy and Gabor filter is used. Firstly Fundus image is obtained from the Drive database and salt and pepper noise is added to image as we are designing this method for highly noisy and corrupted image. Then Fuzzy filter and Gabor filter bank is used to obtain the segmented image. Fig.1 shows the flowchart of proposed method.

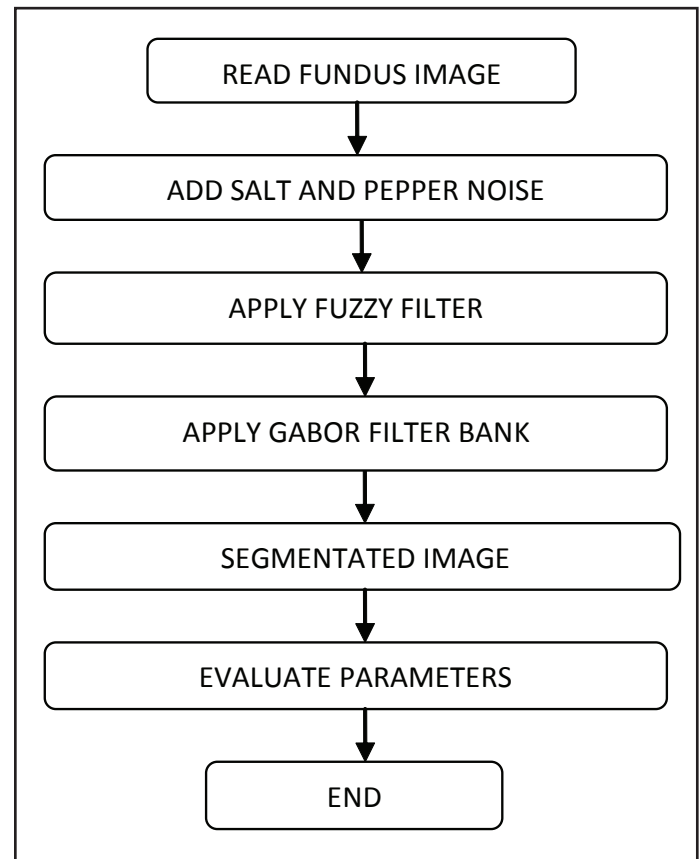


Fig. 1: Flowchart of Proposed Method

A. Fuzzy Filter

Digital images perform an important role in diagnosis of many diseases but images are often contaminated by impulse noises. These noises can deteriorate the quality of the image. Camera sensors, scanners and transmission of image through noisy channels are main reasons of addition of noise in image. Salt and pepper noise is a special case of impulse noise, where certain percentage of individual pixels in digital images is randomly digitized into two extreme intensities [14]. The reduction of salt and pepper noise is quite necessary as presence of this noise can damage information contained in the image. This information is quite necessary in image processing tasks like segmentation.

Fuzzy based median filter is employed to reduce salt and pepper noise from image. Firstly decision based technique [15] is used in which corrupted pixel are substituted by either median pixel or neighborhood pixel. Initially the corrupted pixel and non corrupted pixels are detected from the image based upon the value of the processed pixel. The minimum value is 0 and maximum value is 255. If the value of pixel is greater than 0 and less than 255, then it is noise free pixel. In this case same value of the pixel is retained. If the value of pixel lies out of this range then it is a corrupted pixel. In that case pixel value is replaced by the median value of the selected window. But probability of having median value as corrupted one is also there. In that case pixel value is replaced by the value of previously processed neighborhood pixel. But

even after this, small amount of noise is still there in the image. To remove this noise fuzzy switching is used. Modification of the pixel value is done by the fuzzy switching.

In fuzzy switching noise pixels are fuzzified by membership functions. Correctness factor is used to modify the pixel values. Let $F[P(x, y)]$ is membership function of $P(x, y)$ that specifies the extent to which pixel is corrupted by noise. Then fuzzy rule is applied as

- If $P(x, y)$ is large, then $F[P(x, y)]$ is also large.
- If $P(x, y)$ is small, then $F[P(x, y)]$ is also small.

So when the value of $F[P(x, y)] = 0$, pixel is non-corrupted and same pixel value is retained.

- If $F[P(x, y)] = 1$, then pixel is noisy and filtering is performed.
- When $0 < F[P(x, y)] < 1$, in this pixel is somewhat noisy. Then following equation is used to modify pixel value.

$$P(x, y) = Q(x, y) + F[P(x, y)] * [M(x, y) - Q(x, y)] \quad (1)$$

Where $Q(x, y)$ is current pixel and $M(x, y)$ is a median of pixels in window

B. Gabor Filter

Gabor filter was designed by Dennis Gabor. Gabor filter is used for texture segmentation from image as the frequency and orientation of Gabor filters are analogous to human visual system. The impulse response of Gabor filter is specified by the multiplication of sinusoidal wave and Gaussian function.

Mathematically Gabor filter is defined as [16]

$$g(x) = g_r(x) + i g_i(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} e^{i2\pi f x} \quad (2)$$

Where $\frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}}$ represents Gaussian envelope and f

represents the centre frequency. $e^{i2\pi f x}$ is complex sinusoidal that have real part $g_r(x)$ and imaginary part $g_i(x)$.

Then Daugman designed Gabor filter for 2-D and mathematically it is defined as

$$g(x, y) = e^{-\left(\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right)} \cos(2\pi f x + \varphi) \quad (3)$$

Where σ_x and σ_y represents spread of gaussian envelope and φ is phase sin wave. In implementation only real part of Gabor filter is used.

Different steps performed in segmentation using Gabor filter bank are parameter optimization followed by identifying key points and texton generation.

1. Parameter Optimization

Gabor function makes use of the different parameters to manage the performance of the filter. These different parameters are center frequency (f), phase of sin wave (φ) and spread of gaussian function (σ). Symmetry of the filter kernel depends upon the parameter φ . Orientation parameter θ is used that specifies the orientation of filter kernel. Then equation (3) becomes

$$g_\theta(x, y) = e^{-\left(\frac{1}{2}\left(\frac{x'^2}{\sigma_x^2} + \frac{y'^2}{\sigma_y^2}\right)\right)} \cos(2\pi f x' + \varphi) \quad (4)$$

Where $x' = x \cos \theta + y \sin \theta$
 $y' = -x \sin \theta + y \cos \theta$

Now we consider that the spread of envelope in both the direction are similar so we put $\sigma_x = \sigma_y$. One more parameter γ is used that specifies the ellipticity of the Gabor kernel. This parameter γ is known as the spatial aspect ratio. The frequency f can also be written as $1/\lambda$, where λ is wave length parameter.

$$g_{\lambda, \sigma, \varphi, \theta, \gamma} = e^{-(x'^2 + \gamma^2 y'^2)/(2\sigma^2)} \cos(2\pi(x'/\lambda) + \varphi) \quad (5)$$

Where $x' = x \cos \theta + y \sin \theta$

$y' = -x \sin \theta + y \cos \theta$

Kernel is circular when the spatial aspect ratio is equal to 1 and σ represents the standard deviation of gaussian envelope [17]. As the vessels are dark as compared to the background, we are using value of $\varphi = \pi$. Also the parameters σ and λ are correlated and the only one parameter can be taken as independent. So we are considering λ as a free parameter.

So the Gabor filter bank that is used in this method is parameterized by λ . So, different values of λ are used to extract the vessels from the fundus image. Even performance of single scale is good but tiny vessels are neglected in that method. So we are using a multi scale method where range of scale varies from 4-15.

2. Identifying Keypoints

Potential keypoints are the points of interest in an image. These points are identified from the image using Gabor filter bank. Keypoints are available in the image in main vessels as well as around small capillaries also. So multi scale approach is used to evaluate filter response at every pixel. These different values of scale are used to extract vessels of different widths i.e. thin, wider and tiny vessels. Then filter response for every pixel is compared to its 26 neighbors and then local maxima are found. This helps us to get keypoints at different scales. Then the potential keypoints are extracted by eliminating those points that have low contrast. In implementation we extract best keypoints from the training images. Here all keypoints are signified by a descriptor that is created as dimensional vector. Then these points are matched with the keypoints of the running image. After this, these keypoints are employed to start the clustering process in process of texton generation.

3. Texton Generation

Texton are the small lines, blobs and terminators that signify the small geometric textural structure present in image. These textons are the filter responses at every pixel. Then k means clustering is applied to the filter responses from the training images. Initialization of clustering is done by using the filter response from the potential points and it runs until convergence is achieved. Then to detect textons the cluster having largest size is considered as background and the clusters that are left are considered as vessels. Then for every test image we apply this Gabor filter bank and 1-NN classifier is used to determine whether pixel belongs to vessel or non vessel class.

III. Results and Discussions

Testing and evaluation of proposed method is performed on DRIVE database [18]. The DRIVE database contains 40 color images (768 × 584 pixels) divided into 20 training and 20 test images [19]. Capturing of images is performed using Canon CR5 fundus camera at 45°FOV and images are in tiff format. Mask of each image is also provided to eliminate the rim border surrounding the field of interest. The ground truth images are also provided to evaluate segmentation results.

The existing algorithm [16] and proposed algorithm are implemented using MATLAB and results are obtained for noisy and corrupted fundus images. Fig. 2 shows the results obtained using proposed methods.

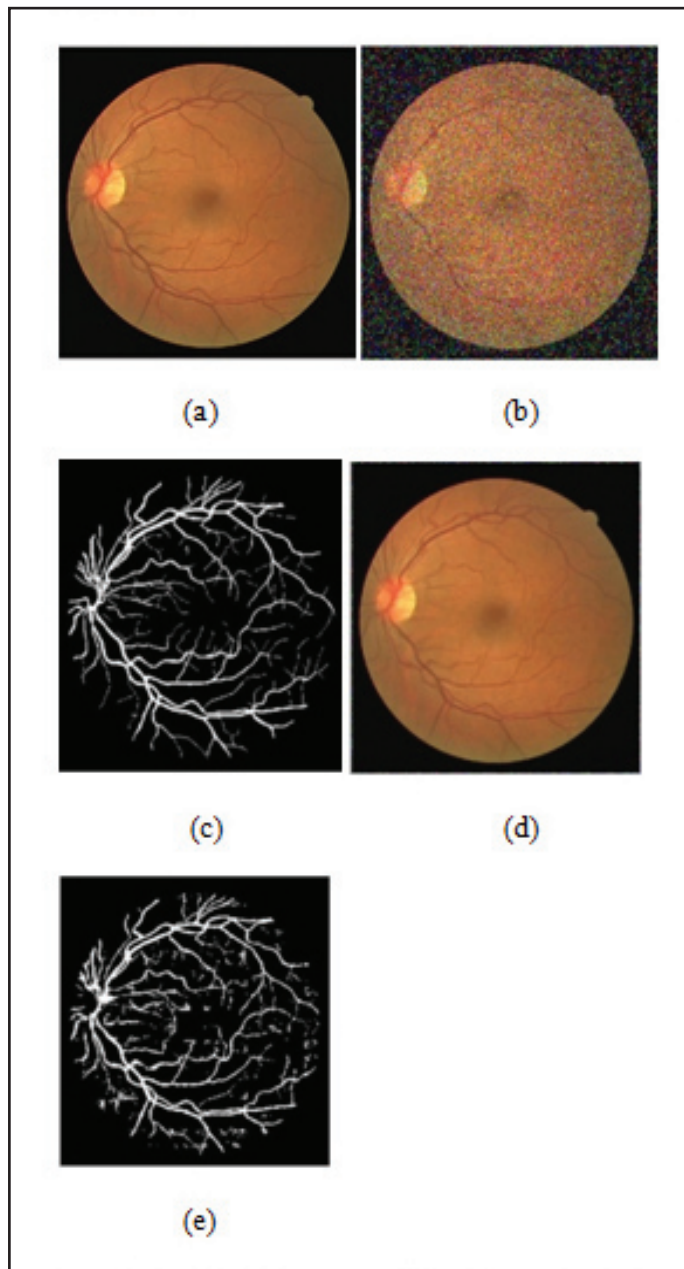


Fig. 2: Results of Proposed Method. (a) Fundus Image (b) Noisy Image (c) Ground Truth Image (d) Image After Fuzzy Filter (e) Final Segmented Image

Then performance evaluation is done using three parameters and values of these parameters obtained using existing and proposed technique are compared. The first one is sensitivity that is calculated as:

$$SEN = \frac{TP}{TP + FN} \quad (7)$$

TP is number of true positive and FN is the number of false negative. Table 1 shows the values of sensitivity for existing and proposed technique.

Table 1: Sensitivity Analysis

Image	Existing	Proposed
1	0.6711	0.8219
2	0.6876	0.8320
3	0.6524	0.7938
4	0.6249	0.7615
5	0.6434	0.7845
6	0.6101	0.7308
7	0.6420	0.7846
8	0.6223	0.7721
9	0.6020	0.7203
10	0.6444	0.7836
11	0.6540	0.7816
12	0.6406	0.7805
13	0.6079	0.7501
14	0.6724	0.8232
15	0.6203	0.7550
16	0.6582	0.8018
17	0.6460	0.7914
18	0.6609	0.7969
19	0.6331	0.7684
20	0.6065	0.7326

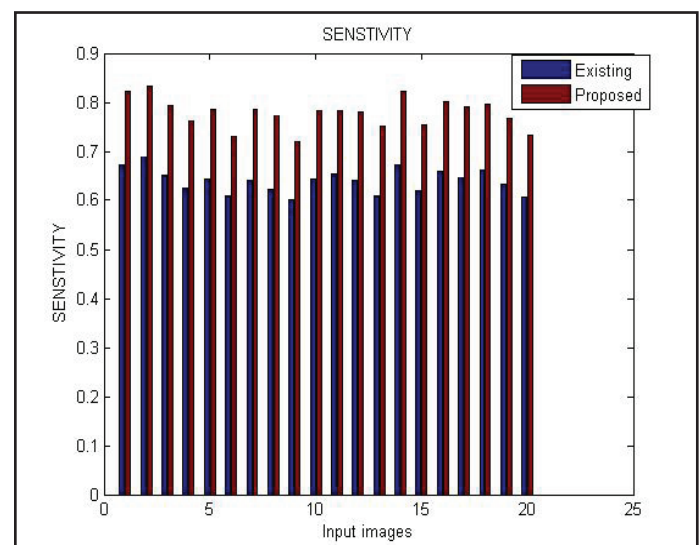


Fig. 3: Sensitivity Analysis

It is seen from fig. 3 that sensitivity is increased in proposed method as compared to existing method.

Accuracy is defined as

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \quad (8)$$

FP is number of false positive and TN is number of true negative. Table 2 shows the value of accuracy for both techniques.

Table 2: Accuracy Analysis

Image	Existing	Proposed
1	0.9360	0.9515
2	0.9384	0.9556
3	0.9342	0.9454
4	0.9311	0.9425
5	0.9366	0.9500
6	0.9271	0.9422
7	0.9373	0.9484
8	0.9344	0.9443
9	0.9282	0.9396
10	0.9371	0.9519
11	0.9344	0.9495
12	0.9353	0.9469
13	0.9239	0.9362
14	0.9429	0.9525
15	0.9353	0.9434
16	0.9382	0.9525
17	0.9373	0.9469
18	0.9330	0.9500
19	0.9281	0.9441
20	0.9258	0.9406

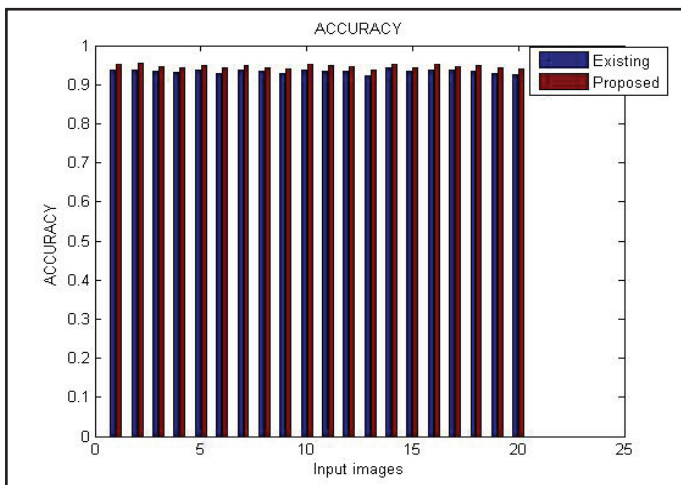


Fig. 4: Accuracy Analysis

Fig. 4 shows that the value of accuracy is improved in proposed method as compared to the existing technique.

Matthews Correlation Coefficient is defined as

$$MCC = \frac{(TP)(TN) - (FP)(FN)}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}} \quad (9)$$

Table 3 shows the value of MCC for existing and proposed technique.

Table 3: MCC Analysis

Image	Existing	Proposed
1	0.6433	0.7479
2	0.6279	0.7445
3	0.6023	0.6947
4	0.5760	0.6699
5	0.5886	0.6940
6	0.5692	0.6705
7	0.5627	0.6635
8	0.5267	0.6267
9	0.5367	0.6282
10	0.5633	0.6791
11	0.5888	0.6955
12	0.5791	0.6779
13	0.5759	0.6702
14	0.6078	0.7022
15	0.5542	0.6406
16	0.6110	0.7184
17	0.5712	0.6660
18	0.6076	0.7198
19	0.5963	0.7017
20	0.5612	0.6638

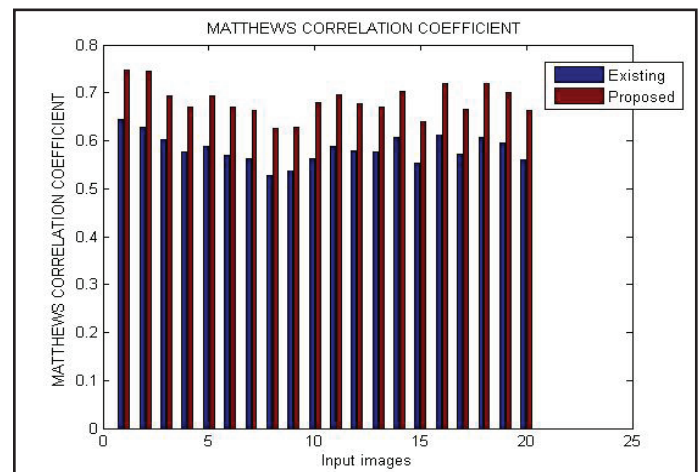


Fig. 5: MCC Analysis

Fig. 5 shows that value of MCC is improved in proposed method.

Results of the proposed method show an average value of sensitivity, accuracy and Matthews correlation coefficient as 0.7783, 0.9466 and 0.6837 respectively for highly noisy and corrupted images. The average value of sensitivity, accuracy and MCC for existing technique are 0.6400, 0.9337 and 0.5824 respectively.

IV. Conclusion

Digital images are often contaminated by impulse noise so in this paper an efficient method of retinal vessel segmentation from highly corrupted and noisy fundus image is presented. The approach uses the combined fuzzy and Gabor filter. We have improved average value of sensitivity to 22% and also enhanced other parameters like accuracy and Matthews Correlation Coefficient etc. as compared to existing technique. High value of sensitivity using proposed method indicates that method is quite efficient in detecting correct vessels.

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