Research Article

IMAGE PROCESSING TECHNIQUES USED IN OPHTHALMOLOGY - BLOOD VESSEL DETECTION IN RETINAL IMAGES

Aman Mukhopadhyay[1]

[1]School of Computer Science and Engineering, VIT University, Vellore, Tamil Nadu, India.
Correspondence should be addressed to: aman.mukhopadhyay2017@vitstudent.ac.in

Academic Editor: Dr. Suresh Kumar N.

Abstract:

The significant health issues among the present generation individuals are eye ailments. One of the most important internal components in eye is called retina. Retina located in the back of the eye is not only a vital part of human sight, but also contains valuable information that can be used in biometric security applications, or for the diagnosis of certain diseases. In this paper, we detect the blood vessels present in the retina and also analyse the various aspects of ophthalmological or ocular ailments such as ocular dysfunctional retinopathy, glaucoma and diabetic retinopathy. We used RGB image for obtaining the traces of blood vessels. We proposed a method to detect blood vessels consists of three phases, Pre- processing, Vesselness Filter and Vessel detection. Also, we proposed an algorithm for detection of diseases in retinal images consists of four main steps: Pre-processing, Segmentation, Feature Extraction and Classifier. The performance of algorithms is compared and analysed on an average basis, and can be comparable to existing ones.

Keywords Used: Eye, Retina, Image processing, Segmentation, blood vessels, Filters

Introduction:

The eye is an important organ that provides the magic of sight. It allows us to observe, react and adapt to surrounding environments by interpreting shapes, colours and dimensions of objects seen. This is accomplished when the lens of the eye focuses light onto the photoreceptive cells of the retina. The photons of light trigger a response by producing neural impulses which are processed by different parts of the brain. The anatomy of the eye seen in Fig.1 can divided into three different layers external, intermediate and internal. The external layer consists of the sclera and cornea. The intermediate layer is split into two parts: iris and ciliary body. The internal layer is the retina.

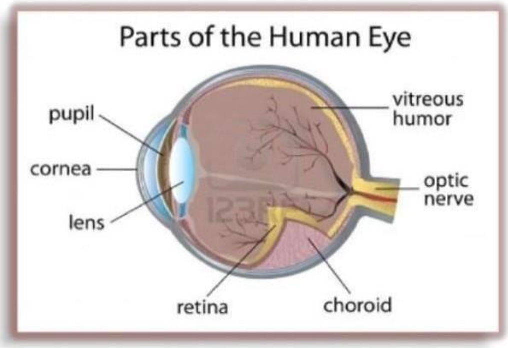

Fig.1: The Human Eye

The cornea is a tough transparent tissue that covers the anterial surface of the eye. Sclera is an opaque membrane that encloses the part of optic globs. It lies directly below the sclera which contains the network of blood vessels. These blood vessels are the major source of nutrients to the eye. Retina is an inner most layer of eye. This is responsible for visualization of external scenario. It is a thin layer of tissue in the back of the eye that senses light and sends images to your brain. In the centre of retina there is the optic disk, a circular to oval shape. From the centre of optical nerve radiates the major blood vessels of the retina. The blood vessels network is an important anatomical structure in human retina, which is use to recognize different types of disease. However, manual detection of blood vessels is not simple because the vessels in retina image are complex and have low contrast. For retinal anatomy ophthalmologist uses an ophthalmoscope. The retinal fundus image is widely used in the diagnosis and treatment of various types' diseases such as diabetic retinopathy and glaucoma.

This work consists of automated segmentation of vasculature of retinal images which can be used in diagnostic of various eye diseases. Different retinal vessel segmentation methodologies have been published and assessed in literature but they still need some improvement. Existing systems should be enhanced in terms of at least one of the following drawbacks. Firstly, lack of adaptive capabilities under varying image conditions may cause poor quality of segmentation such as under and over segmentations. Secondly, complex pre-processing and postprocessing operations used in different methods for extracting retinal images vessels caused high computational cost. Thirdly, human participation is required to choose area of interest, which demonstrates that the systems are not totally automatic. In conclusion, segmentation and assessment procedures themselves need large computational endeavours. In literature, many retinal segmentation methods are designed from the line detection methods, as vessel segmentation depends on line detection. Generally, vessel segmentation methods consist of two steps: vessels enhancement and vessels classification. Some techniques may escape first step and use directly the second step. In the first step vessels are enhanced, noise and geometrical objects are removed. Chaudhuri et al., first proposed matched filter to enhance and segment retinal vessels. Further improvements and similar techniques were proposed later on by various authors using threshold probing technique, double-sided thresholding and the first order derivative of Gaussian image. Matched filters application for segmentation, produced high quality results at the cost of long computational time. The quality of segmentation results mainly depends on the quality and size of the used vessel profile database. Retinal blood vessels have been enhanced by using Gabor filter. This methodology has a great performance on normal retinal images. Lam and Yan, used laplacian operator and gradient vector fields to extract vessels. Staal et al. proposed a framework depends on extraction of image ridges, which correspond roughly with vessel centrelines. Zana Klein and Mendonça Campilho used morphological filters to enhance vessels. Their proposed method showed better results than most of the existing techniques on the pathological retina. Martínez-Pérez et al. were also based on hessian matrix to extract multiscale feature for detection of vessels. Vessel enhancement filter was designed on the base of hessian matrix. After vessel enhancement, second step is the classification of pixels into vessel and non-vessel pixels. This second step is also known as vessel tracking and tracing. Pixels intensities based classification is used to find a suitable threshold. Jiang and Mojon performed adaptive local thresholding to extract vessels. Support Vector Machine (SVM) is used along with adaptive local thresholding to classify vessel and non-vessel pixels. Zhou et al. method is based on prior knowledge about retinal vessel characteristics coupled with matched filtering technique to detect the vessel structure. Al-Diri utilized two pairs of contours to detect vessel boundary and sustain width of vessels. Fraz et al. used first-order derivative of Gaussian filter to extract centrelines of retinal vessels before mathematical morphology to quantify vessels in retina. Generally, all vessel extraction methods can be classified into supervised segmentation and unsupervised segmentation with the reference to the overall system design and structure.

LITERATURE REVIEW:

[1] Archna Sharma and Hempriya have proposed a method for Detection of Blood Vessels and Diseases in Human Retinal Images. In this the detection of blood vessels is important task in diagnosis the diseases of eye. The present study is aimed at developing an automated system for the extraction of normal and abnormal features in retinal images. The blood vessel network is an important anatomical structure in human retina. Several diseases such as Diabetic retinopathy, glaucoma, hemorrhages, and the performance of automatic detection methods may be improved if regions containing vessels can be excluded from the analysis.

[2] Megha Lotankar, Kevin Noronha, Jayasudha Koti have proposed a method for Detection of Optic Disc and Cup from color Retinal Images for Automated Diagnosis of Glaucoma. In this paper the Detection of Optic Disc and Cup is important task in diagnosis the Glaucoma. Automated glaucoma detection system based on the four features vertical CDR, CDAR, H-V.CDR and RDAR is presented in this paper. This paper uses OD segmentation for accurate segmentation results. Finally by using SVM, NB and KNN classifier the fundus retinal images into Glaucoma class and Normal class.

[3] A.Elbalaoui, M. Fakir and K. Taifi, A. Merbouha, has proposed a method on" Automatic Detection of Blood Vessel in Retinal Imag**es",** In this paper experimentations are performed on all three publicly available retinal image databases, namely, DRIVE, STARE and CHASE. In this they use a segmentation algorithm for detection purpose, before segmentation they apply image enhancements on retinal images for improve the quality of image. Algorithm for detection of blood vessels has the advantage that it is applicable to all types of retinal images, healthy as well as abnormal.

[4] Minal Wankhade and Dr. A. A. Gurjar have proposed "Analysis Of Disease using Retinal Blood Vessels Detection". In this paper they found the disease such as diabetes, glaucoma and hemorrhage on the basis of their segmentation. In this paper they used a proposed methodology such as Image acquisition, Image segmentation and feature extraction.

A BRIEF OVERVIEW:

Blood vessels detection is an important but difficult task during surgeries. An unexpected location of a blood vessel or anatomical variations may results in an accidental injury to the blood vessel. This problem would extend the operation time or cause a serious complication. Following steps are used for blood vessel detection. The first step is pre-processing of retinal image to improve the retinal images. To enhance the blood vessels we used vesselness filter in second step. In final step, Hessian multiscale enhancement filter is designed from the adaptive thresholding of the output of the vesselness filter for vessels detection.
The proposed method for diseases detection consists of following main steps i.e. Pre-processing, Segmentation, Feature Extraction, Classifier.

A. Pre-processing 1) Image Resize: In this step we can change the image size. Resizing an image will not affect the screen display.

   2) RGB to HSV processing: HSV is a color model that is often used in place of RGB color model. By using HSV color model, a color is specified then white or black is added to easily make color adjustment.

   3) Filtering: To reduce the distortion or noise in the image.

   4) CLAHE: We use CLAHE because it can increase the contrast between contours.

B. Segmentation:
C. Feature Extraction:
D. Classifier:

The main objective of pre-processing technique is to attenuate image variation by normalizing the original retinal image.

Pre-processing steps are as follows:
The goal of segmentation is to simplify an image into something that is more meaningful and easy to analyze. Retinal vessel segmentation is an essential step of the diagnosis of various eye diseases [3]. Segmentation is used in compression to compress different areas, segments of an image, at different compression quality. In this stage, blood vessels are segmented properly using Super pixel segmentation. Super pixel segmentation is used to reduce the input entities for the subsequent algorithm. Once the image is divided by using segmentation then we extract features in image. Feature Extraction plays a very important role in the area of image processing. The main goal of Feature Extraction is to obtain more relevant information in a lower space. We use HOG technique to extract features. HOG calculates gradient magnitude and gradient angle for each pixel in a block.
In our methodology, we use Random Forest classifier. Random Forest is a flexible, ease to use machine learning algorithm that produces, even without hyper parameter tuning, a great result most of the time. This classifier is used for both classification and regression tasks. Another great quality of Random Forest algorithm is that it is very easy to measure the relative importance of each feature on the prediction.

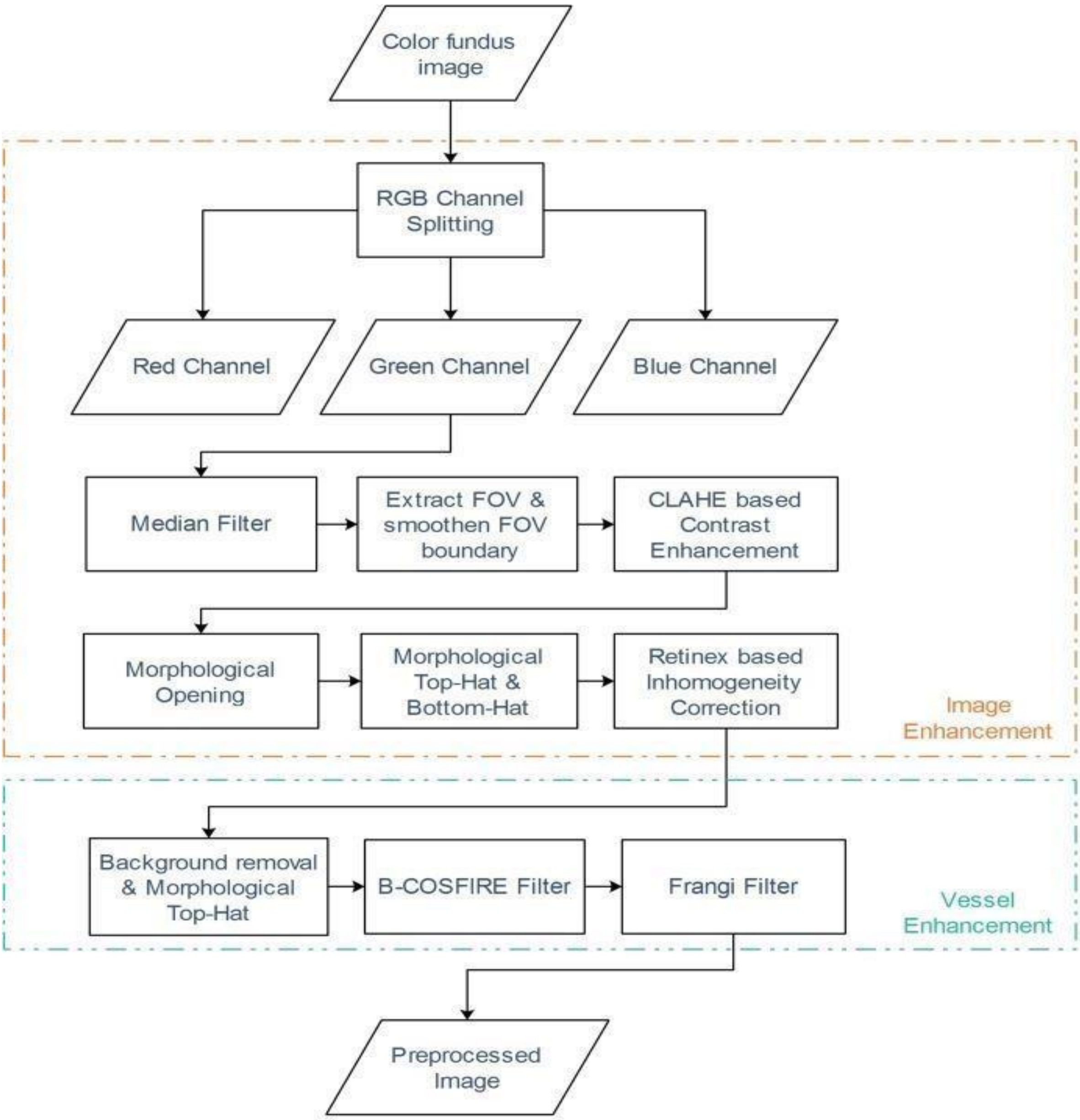

Fig. 2: Pre-processing and Vessel enhancement steps

Preprocessing and vessel enhancement:

Based on Retinex theorem, any given image I can be represented as a component-wise multiplication of its reflectance R and illumination L as: $I = R \times L$

Let's denote x as a pixel belonging to image I, the pixel x of the reflectance image $R(x)$ could be obtained by computing the difference of the logarithms between the original image $I(x)$ and the resulting image $L(x)$ after applying a bilateral filter to the original image $I(x)$, defined as:

$$R(x) = \log(I(x) + 1) - \log(L(x) + 1)$$

$$L(x) = M^{-1}(x)\int_w I(\ell)g(\ell, x)s(\ell, x)d\ell$$

$$M(x) = \int_w g(\ell, x)s(\ell, x)d\ell$$

$$g\left(1, x\right) = e^{-\frac{1}{2}\left(\frac{d(1,x)}{\sigma_d}\right)^2}$$

$$s\left(1, x\right) = e^{-\frac{1}{2}\left(\frac{d(I(1),I(x))}{\sigma_r}\right)^2}$$

Afterwards, the image background is computed and removed by subtracting the image from its median filtered image using a large kernel.

B-COSFIRE filter: Bar-selective combination of shifted filter responses (B-COSFIRE) was proposed by Azzopardi et al. for detection of patterns with a bar shape. Vessels are enhanced with B-COSFIRE filter by using a bank of collinearly aligned Difference of Gaussian (DoG) filters that have been configured for detecting the bar-like appearance of blood vessels at different angles. A DoG filter for detecting the intensity variations of the image can be defined as:

$$DoG\left(x, y\right) = \frac{1}{2\pi\sigma^2}exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) - \frac{1}{2\pi(0.5\sigma)^2}exp\left(-\frac{x^2+y^2}{2(0.5\sigma)^2}\right)$$

Where σ denotes the standard deviation of the Gaussian function. The response $c_\sigma(x,y)$ of a DoG filter is computed by convolving image $I(x,y)$ with $DoG(x,y)$ while replacing any negative values with zero.

$$S=\{(\rho_i, \Phi_i)|i = 1, \ldots n\}$$

The DoG filter response $s_{\rho i},\Phi_i(x, y)$ at each position (ρ_i,Φ_i) is computed as:

$$s_{\rho_i,\Phi_i}\left(x,y\right) = \underbrace{max}_{x^{'},y^{'}}\left\{c_\sigma\left(x-\Delta x_i - x^{'} - \Delta y_i - y^{'}\right)G_{\sigma^{'}}\left(x^{'},y^{'}\right)\right\}$$

Frangi filter : Frangi filters were first proposed for enhancing the vessel profiles in coronary artery segmentation. Hessian matrix based Frangi filter is a popular approach that is both efficient and requires less computation time . The Hessian matrix is constructed by computing the vertical and horizontal diagonals of the second-order derivative of the image. The Hessian based Frangi filter can be defined as:

$$F(x) = max_\sigma f(x, \sigma)$$

Where the pixel of interest is defined by x, the standard deviation for computing the Gaussian derivative of the image is denoted as σ and f represents the filter. The hessian matrix can be defined as:

$$\mathrm{H} = \begin{pmatrix} H_{xx} & H_{xy} \\ H_{yx} & H_{yy} \end{pmatrix}$$

Where H_{xx}, H_{xy}, H_{yx} and H_{yy} represent the directional second-order partial derivatives of the image. Let's denote λ_1 and λ_2 as the eigenvalues of H, these are used for determining the probability of the pixel of interest x being a vessel based on the following notions:

$$|\lambda 1| \leq |\lambda 2| > 0 \text{ and } f(x, \sigma) = 0$$

Then, the Hessian based Frangi filter can be defined as:

$$f\left(x\right) = \begin{cases} 0 & , if\ \lambda_2 > o \\ e^{\left(-\frac{R_b^2}{2\ \alpha^2}\right)}\left(1 - e^{\left(\frac{S^2}{2\beta^2}\right)}\right), & elsewhere \end{cases}$$

$$R_b = \frac{|\lambda_1|}{|\lambda_2|},\ S = \sqrt{\lambda_1^2 + \lambda_2^2}$$

Extracting image features Intensity based image features - Extracting image features:

The accuracy of machine learning based supervised segmentation approaches is highly dependent on the set of features being utilized. Thus, it is necessary to select the best set of features for a good separation between the vessels and the background. Sole use of intensity values as features is not that accurate and reliable and spatial relations between neighbouring pixels should also be included in the features. In this study, a sliding window is used for extracting image features for each of the image pixels by considering a predefined set of pixels in the neighbourhood of each pixel.

Intensity based features can be used to represent some texture characteristics of the image using the distribution of intensities inside the image. These features are mostly calculated using the image histogram. Given an image *I* with size *n*, these features are defined as:

$$\text{Mean} = \frac{1}{n^2} \sum_{(i,j)\in[1:n]^2} I_{i,j}$$

$$\text{Variance} = \frac{1}{n^2} \sum_{(i,j)\in[1:n]^2} \left(I_{i,j} - mean\right)^2$$

$$\text{Skewness} = \frac{1}{n^2} \sum_{(i,j)\in[1:n]^2} \left(I_{i,j} - mean\right)^3$$

$$\text{Kurtosis} = \frac{1}{n^2} \sum_{(i,j)\in[1:n]^2} \left(I_{i,j} - mean\right)^4$$

Pseudo-Code:

```
% READ IMAGES
eye1 = imread('Retina1.png');

%display coloured version(original)
imshow(eye1);

% convert to grayscale
grayeye1 =rgb2gray(eye1);

% display grayscale
imshow(grayeye1);

% make darker
dgrayeye1 = imadjust(grayeye1,[0.1 0.9],[]);
imshow(a);
se = strel('disk',1);
```

```
cannyeye = edge(dgrayeye1,'canny',0.15);
figure,imshow(cannyeye);

% dilate image
dilate = imdilate(cannyeye,se);
figure, imshow(dilate)

% image segmentation
segmentedimg = features/(1+numel(Ls));

%noise filtering
for i = 1:nobjs
   cur_obj = find(segmentedimg_lb == i);
   cur_size = numel(cur_obj);
   if cur_size > noisesize
      postprocessedimg(cur_obj) = 1

%standardise image
function simg = globalstandardize(img,mask)
```

Results and Discussion:

Fig.2: Sample Test image from dataset

Fig.3: Image with background normalisation

Fig.4: Detail-preserved, noise-removed image

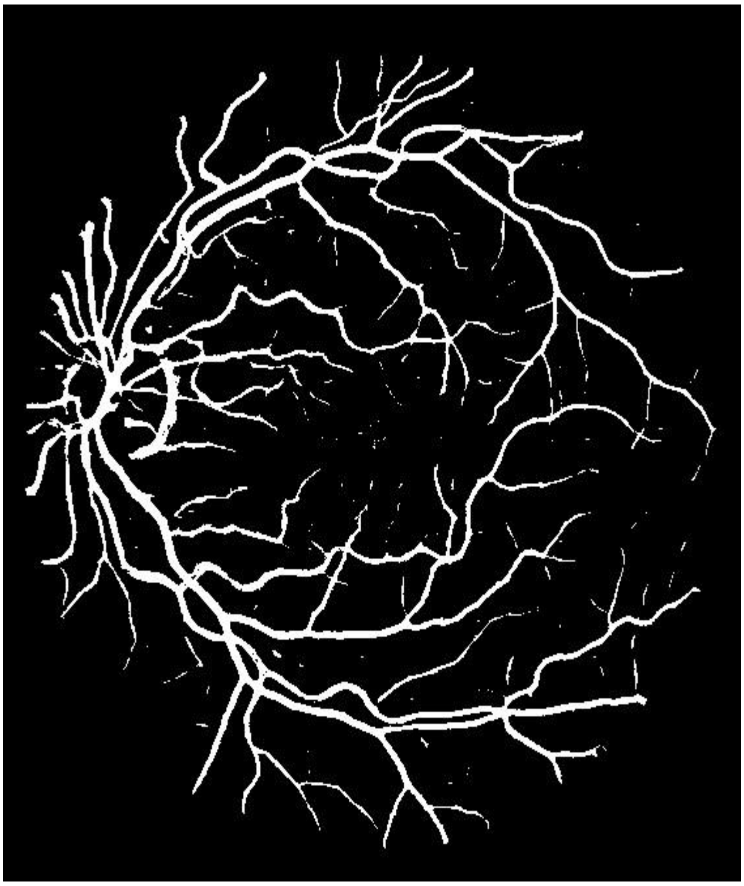

Fig.5: Final pre-processed image after applying filter

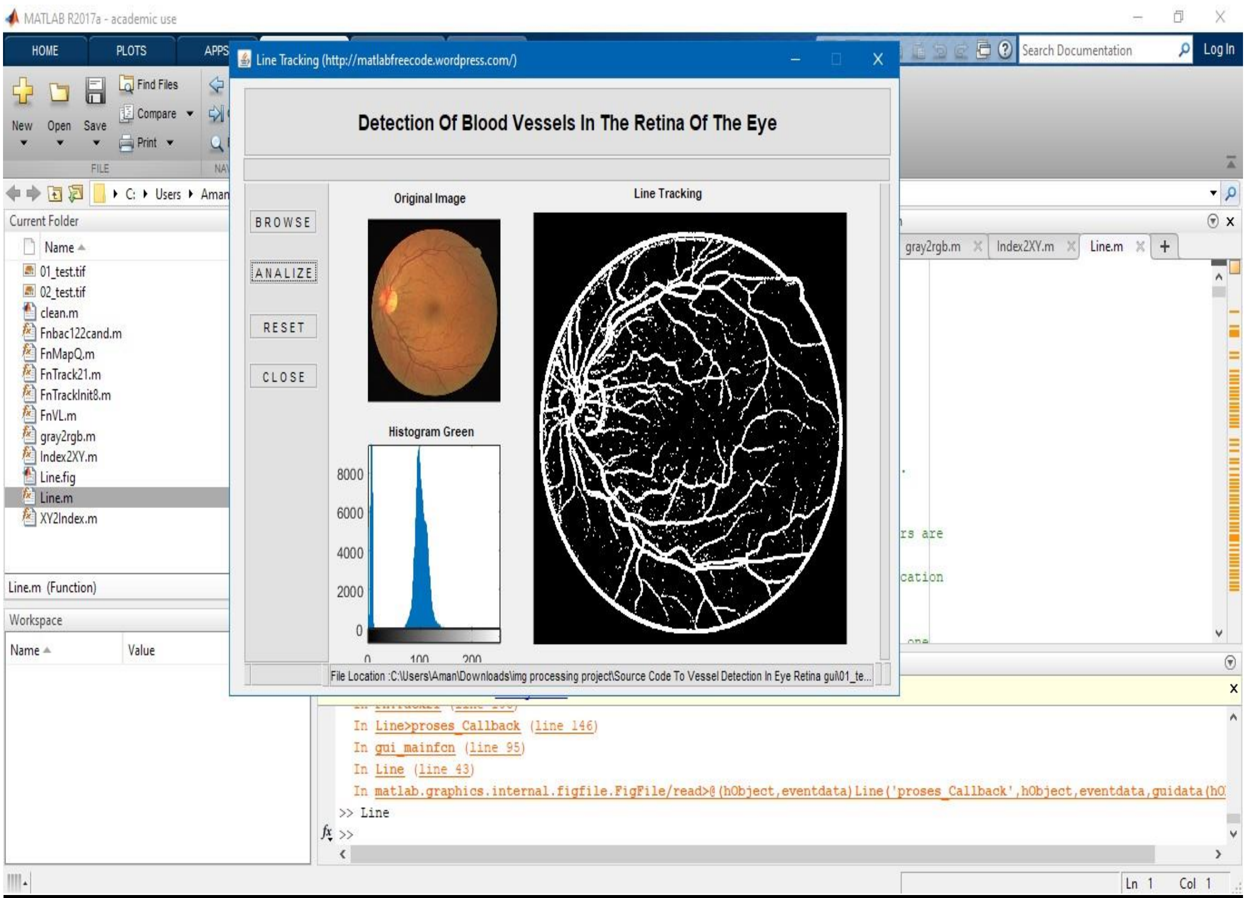

Fig.6: GUI (Graphical User Interface) made in MATLAB

Potential Limiting factors affecting the project :

It can be observed that the segmentation result is not very accurate. This is most likely caused by using a very small training set (to make testing convenient). It could also be a undetected bug in our code (potentially in the function “matlab:determine_threshold”).

Moreover, Matlab's built-in morphological operations produce slightly different results than the paper. This could potentially be an error in choosing our structural element when applying the operations.

Conclusions:

Vessel segmentation can be considered as an important step toward automated retina analysis tools. The segmented vessels can be used for advanced retina image analysis such as computing the vessel tortuosity and diameter, differentiating arteries and veins along with measuring the arteriovenous ratio. Moreover, segmented vessels are routinely used as features in retinal disease classification systems that are used for identification of several systematic diseases such as stroke, hypertension or diabetes, to name a few. In this paper, a supervised retinal vessel segmentation algorithm based on matched filters and classifiers is proposed. The proposed method could handle pathological retina images and produces good segmentation, especially in thinner vessels.

Bibliography and References:

1. Fraz MM, Remagnino P, Hoppe A, Uyyanonvara B, Rudnicka AR, Owen CG, et al. Blood vessel segmentation methodologies in retinal images–a survey. Comput Methods Programs Biomed. 2012;108(1):407–33. doi: 10.1016/j.cmpb.2012.03.009 [PubMed] [Google Scholar]
2. Solkar SD, Das L. Survey on Retinal Blood Vessels Segmentation Techniques for Detection of Diabetic Retinopathy. Diabetes. 2017. [Google Scholar]
3. Singh N, Kaur L, editors. A survey on blood vessel segmentation methods in retinal images. Electronic Design, Computer Networks & Automated Verification (EDCAV), 2015 International Conference on IEEE. 2015: 23-28. 10.1109/EDCAV.2015.7060532
4. Meng X, Yin Y, Yang G, Han Z, Yan X. A framework for retinal vasculature segmentation based on matched filters. Biomedical engineering online. 2015;14(1):94 doi: 10.1186/s12938-015-0089- 2 [PMC free article] [PubMed] [Google Scholar]
5. Chaudhuri S, Chatterjee S, Katz N, Nelson M, Goldbaum M. Detection of blood vessels in retinal images using two-dimensional matched filters. IEEE Trans Med Imaging. 1989;8(3):263–9. doi: 10.1109/42.34715 [PubMed] [Google Scholar]
6. Li H, Hsu W, Lee ML, Wong TY. Automatic grading of retinal vessel caliber. IEEE Trans Biomed Eng. 2005;52(7):1352–5. doi: 10.1109/TBME.2005.847402 [PubMed] [Google Scholar]
7. Zhou L, Rzeszotarski MS, Singerman LJ, Chokreff JM. The detection and quantification of retinopathy using digital angiograms. IEEE Trans Med Imaging. 1994;13(4):619–26. doi: 10.1109/42.363106 [PubMed] [Google Scholar]

8. Yin Y, Adel M, Bourennane S. Retinal vessel segmentation using a probabilistic tracking method. Pattern Recognition. 2012;45(4):1235–44. doi: 10.1016/j.patcog.2011.09.019 [Google Scholar]

9. Wink O, Niessen WJ, Viergever MA. Multiscale vessel tracking. IEEE Trans Med Imaging. 2004;23(1):130–3. doi: 10.1109/TMI.2003.819920 [PubMed] [Google Scholar]

10. Zhang B, Zhang L, Zhang L, Karray F. Retinal vessel extraction by matched filter with first-order derivative of Gaussian. Computers in biology and medicine. 2010;40(4):438–45. doi: 10.1016/j.compbiomed.2010.02.008 [PubMed] [Google Scholar]

11. Gang L, Chutatape O, Krishnan SM. Detection and measurement of retinal vessels in fundus images using amplitude modified second-order Gaussian filter. IEEE Trans Biomed Eng. 2002;49(2):168–72. doi: 10.1109/10.979356 [PubMed] [Google Scholar]

12. Bankhead P, Scholfield CN, McGeown JG, Curtis TM. Fast retinal vessel detection and measurement using wavelets and edge location refinement. PLoS One. 2012;7(3):e32435 doi: 10.1371/journal.pone.0032435 [PMC free article] [PubMed] [Google Scholar]

13. Wang Y, Ji G, Lin P, Trucco E. Retinal vessel segmentation using multiwavelet kernels and multiscale hierarchical decomposition. Pattern Recognition. 2013;46(8):2117–33. doi: 10.1016/j.patcog.2012.12.014 [Google Scholar]

14. Oliveira WS, Teixeira JV, Ren TI, Cavalcanti GD, Sijbers J. Unsupervised retinal vessel segmentation using combined filters. PLoS One. 2016;11(2):e0149943 doi: 10.1371/journal.pone.0149943 [PMC free article] [PubMed] [Google Scholar]

15. Azzopardi G, Strisciuglio N, Vento M, Petkov N. Trainable COSFRE filters for vessel deldineation with application to etinal images. Med Image Anal. 2015;19(1):46–57. doi: 10.1016/j.media.2014.08.002 [PubMed] [Google Scholar]

16. Azzopardi G, Petkov N. Automatic detection of vascular bifurcations in segmented retinal images using trainable COSFIRE filters. Pattern Recognition Letters. 2013;34(8):922–33. doi: 10.1016/j.patrec.2012.11.002 [Google Scholar]

17. BahadarKhan K, Khaliq AA, Shahid M. A Morphological Hessian Based Approach for Retinal Blood Vessels Segmentation and Denoising Using Region Based Otsu Thresholding. PLoS One. 2016;11(7):e0158996 doi: 10.1371/journal.pone.0158996 [PMC free article] [PubMed] [Google Scholar]

18. Niemeijer M, Staal J, van Ginneken B, Loog M, Abramoff MD, editors. Comparative study of retinal vessel segmentation methods on a new publicly available database. SPIE medical imaging. 2004;5370:648–656. doi: 10.1117/12.535349 [Google Scholar]