Retinal Blood Vessel Segmentation Using Edge Detection Method

Sayan Chatterjee\textsuperscript{a}, Amit Suman\textsuperscript{b}, Rishikesh Gaurav\textsuperscript{c}, Sampriti Banerjee\textsuperscript{d}, Ajay Kumar Singh\textsuperscript{e}, Birendra Krishna Ghosh\textsuperscript{f}, Rajat Kumar Mandal\textsuperscript{g}, Mainak Biswas\textsuperscript{h}, Debasis Maji\textsuperscript{i}

\textsuperscript{a}Senior System Engineer, Cognizant Technology Solutions, Kolkata-700156, India.
\textsuperscript{b,c,d,e,f,g,h,i}Department of Electrical Engineering, Techno International New Town, Rajarhat, Kolkata-700156, India.

E-mail: \textsuperscript{a}hiisayan@gmail.com, \textsuperscript{b}amit04.suman@gmail.com, \textsuperscript{c}beingrg07@gmail.com, \textsuperscript{d}sampritibanerjee309@gmail.com, \textsuperscript{e}ajay7gpj@gmail.com, \textsuperscript{f}birendraee@gmail.com, \textsuperscript{g}rajat.mandal.ee.07@gmail.com, \textsuperscript{h}mainakbiswas041@gmail.com, \textsuperscript{i}debasis.maji39@gmail.com

Abstract. Currently eye disease is a major challenge in our life. The main diseases in human eye are Ocular Hypertension, Glaucoma, Diabetic Muscular Edema, Diabetic Retinopathy, Color Blindness, Phonetic, Blindness etc. The only way is to identify the cause and then the treatment could be stared as early as possible. To detect in 1st stage, the measurement as well as automatic tracking of the blood vessels of human eye are very essential task. The photograph of human eye is called Fundus image. To detect the eye vessels, segmentation of these vessels are the main motivation of the work. Here, a survey is being done to do the detection using various edge based segmentation procedures, i.e., Kirsch filter, Canny, Prewitt, Sobel and Fuzzy-C. The work is applied on freely available DRIVE database. The result shows that, Kirsch filter is the best among the other benchmark methods when the results are evaluated for the parameters such as, Accuracy, Specificity and Sensitivity. The outcome of Accuracy is varies from 0.77 to 0.94, Specificity varies in the range between 0.76 to 1.00 and finally Sensitivity lies between 0.20 to 0.84.

1. Introduction

The main motivation of the work is to find the tortuosity of the main vessel of retina, so that the patients suffering from Diabetics and the health condition of pre-mature baby could be diagnosis easily and precisely. The originate of the main vessel is from Optic Disk. Images are mostly affected by noise to a large extent, which cannot be explained by varying data, perturbation in image intensities may be uninterruptable or not desirable. To simplify analysis of image noise is often filtered out. In the field of chemistry, filters are mainly used to free liquid particles from suspended impurities in analogous way by letting them pass through a layer of charcoal or may be sand in some cases. Image filters have many uses like they can be used to emphasizes the edges — i.e., boundaries between parts of objects or the object as whole in images. Filters are used to provide a visual interpretation [1] of morphological images, and may also use as a precursor to digital image processing, such as retinal blood vessel segmentation. Here DRIVE database is used for calculation of the problem statement as stated above. The result is being compared
with the provided ground truth, and the result shows a massive success when it is compared with other benchmark methods. At first the Introduction is narrated, then the techniques are illustrated and the Conclusion and Discussion is there followed by the Result section.

2. Methods
In this work mainly edge based segmentation model is discussed. The framework is not only very fast for execution but also the result is very accurate, which makes it eminent.

2.1. Kirsch filter
Kirsch filter is mainly a nonlinear filter which has the capability of edge detection. It easily calculates the highest edge strength in certain specified directions \([2, 3]\). The maximum magnitude can be defined as:

\[
H_{n,m} = \max_{z=1, \ldots, 8} \sum_{k=-1}^{1} \sum_{l=-1}^{1} y_{kl} b_{n+k,m+l}
\]  

(1)

Kirsch filter is generally used to extract initial edges and after that thin edges which are the task of a derivative mask. \(Z=\) enumerates the compass direction kernels \(y\).

\[
y^1 = \begin{pmatrix} +5 & +5 & +5 \\ -3 & 0 & -3 \\ -3 & -3 & -3 \end{pmatrix}
\]

\[
y^2 = \begin{pmatrix} +5 & +5 & -3 \\ +5 & 0 & -3 \\ -3 & -3 & -3 \end{pmatrix}
\]

\[
y^3 = \begin{pmatrix} +5 & -3 & -3 \\ +5 & 0 & -3 \\ +5 & -3 & -3 \end{pmatrix}
\]

\[
y^4 = \begin{pmatrix} -3 & -3 & -3 \\ +5 & 0 & -3 \\ +5 & +5 & -3 \end{pmatrix}
\]

All the pixels of the given image use these eight masking to make the convolution. Kirsch operator takes kernel mask and then rotates it by 45 degree. The magnitude of the edges is simply calculated by the highest in all directions.

2.2. Fuzzy C Means
All most all algorithms of fuzzy clustering have its origin from fuzzy c-means (FCM) and were in use extensively in medical image processing. Sometimes fuzzy c-mean clustering is also known by the name fuzzy ISODATA. Here every data point belongs to the cluster, to the degree which is generally specified by the membership grades. This method is considered as one of the best method for segmenting blood vessels from fundus image \([4, 5]\) processing for assigning multi class memberships values the pixels of the image.
2.3. Canny Edge Detection

The primary function of the Canny operator is to detect the edge by the use of a multi-stage algorithm in the input image. Due to its various advantages in image processing it is used extensively in computer vision system like vessel extraction from fundus image [6, 7]. Response of the filter can be given by [8],

$$I_G = \int_{-X}^{X} G(-y)f(y)dy$$  \hspace{1cm} (2)

Where, \(G(y)=\)Edge \(f(y)=\) Filter’s impulse response, which is bounded by the range +X to –X Then the R.M.S. response can be given by,

$$I_a = \sqrt{a_0^2 \int_{-X}^{X} f^2(y)dy}$$  \hspace{1cm} (3)

Where, \(a_0^2\) = R.M.S. value of noise amplitude (per unit length) Output Signal-to-Noise ratio is given by,

$$S.N.R = \frac{\int_{-X}^{X} G(-y)f(y)dy}{\sqrt{a_0^2 \int_{-X}^{X} f^2(y)dy}}$$  \hspace{1cm} (4)

Let, \(I_a(y)\) = filter response to noise. \(l_h(y)\) = filter response to edges. At \(y= y_0\) there is a local maximum in the whole response. So,

$$I_{a}'(y_0) + I_{h}'(y_0) = 0$$  \hspace{1cm} (5)

Taylor expansion of \(I_h(0) = 0\)

$$I_{h}'(y_0) = I_{h}'(0) + I_{h}''(y_0) + P(y_0^2) = 0$$  \hspace{1cm} (6)

From equation 5 and 6, we get

$$I_{h}''(y_0) = -I_{a}'(y_0)$$  \hspace{1cm} (7)

\(I_{a}'(y_0)\) is Gaussian random quantity.

$$E[I_{a}'(y_0^2)] = y_0^2 \int_{-X}^{X} f^{'2}(y)dy$$  \hspace{1cm} (8)

$$E(y_0^2) = \frac{a_0^2 \int_{-X}^{X} f^{'2}(y)dy}{[\int_{-X}^{X} G'(-y)f(y)dy]^2} = \delta y_0^2$$  \hspace{1cm} (9)

Localization = reciprocal of \(\delta y_0\) So,

$$Localization = \frac{\int_{-X}^{X} G'(-y)f'(y)dy}{a_0 \sqrt{\int_{-X}^{X} f^{'2}(y)dy}}$$  \hspace{1cm} (10)

In order to reduce the design problem, we have to maximize the product of equation 4 and equation 10

$$\frac{\int_{-X}^{X} G(-y)f(y)dy}{\sqrt{a_0^2 \int_{-X}^{X} f^2(y)dy}} = \frac{\int_{-X}^{X} G'(-y)f'(y)dy}{a_0 \sqrt{\int_{-X}^{X} f^{'2}(y)dy}}$$  \hspace{1cm} (11)
2.4. Prewitt Edge Detection

Edge detection of the desired image is the main responsibility of the Prewitt operator [9]. Similar to the Sobel filter it mainly detects two types: Vertical edges, Horizontal edges. The ground principal of operation of the Prewitt filter is by calculating difference between the corresponding pixels intensities of the image and hence the edges are calculated. Let a continuous image be f(g,h) with g and h respectively be the row and column co-ordinates and $\delta_g f(g,h)$ and $\delta_h f(g,h)$ are typical two directional derivatives. The gradient magnitude can be given by [10],

$$|\text{Magnitude}| = \Delta f(g,h) = \sqrt{(\delta_g f(g,h))^2 + (\delta_h f(g,h))^2}$$  \hspace{1cm} (12)

The gradient orientation can be given by:

$$\text{Phase} = \Delta f(g,h) = \text{ArcTan}(\delta_h f(g,h))/(\delta_g f(g,h))$$  \hspace{1cm} (13)

2.5. Sobel Edge Detection

The Sobel operator is somewhat quite similar to the Prewitt operator. The main function of the Sobel filter is for edge detection. It is a derivate mask. Sobel filter can be easily implemented in both Software and Hardware for detecting vessels from fundus image [11]. The only requirement is that eight points around an image point is enough to calculate the required result and integer arithmetic is required to calculate the gradients vector approximations. The components of vector gradient measure the change in pixel with distance in both the two-dimensional quadrants (let them be $m$ and $n$). So, the approximation made to find the gradient components can be given by [12],

$$\frac{\delta f(m,n)}{\phi y} = \Delta m = \frac{f(m + dm, n) - f(m,n)}{dm}$$  \hspace{1cm} (14)

$$\frac{\delta f(m,n)}{\phi y} = \Delta n = \frac{f(m,n + dn) - f(m,n)}{dn}$$  \hspace{1cm} (15)

Here $dm$ and $dn$ denotes the distance along respectively $m$ and $n$ axis. In discrete images we consider $dm=dn=1$ pixel co-ordinates in this point are $(k,l)$. Then,

$$\Delta m = f(k + 1, l) - f(k, l)$$  \hspace{1cm} (16)

$$\Delta n = f(k, l + 1) - f(k, l)$$  \hspace{1cm} (17)

By calculating the gradient change at $(k,l)$ we can detect the discontinuity of gradient and that can be given by the magnitude and the direction of the gradient are

$$N = \sqrt{(\Delta m)^2 + (\Delta n)^2}$$  \hspace{1cm} (18)

$$\phi = \tan^{-1}\frac{\Delta m}{\Delta n}$$  \hspace{1cm} (19)

3. Results

The work is done by using DRIVE database where 20 images of different patients with different age groups (25 to 90) are there with their corresponding ground truth marked by the Doctors, the size is each image sample is 768X584X3 and in .jpeg image format and the size of the ground truth is 768X584, which is in binary format. The experiment is being examined in MATLAB R2013a (Core i3, 16 GB RAM). The process is executed for 10 times and the mean result is noted. For calculating the results, the following mathematical expressions are used.
Figure 1. Flowchart of the entire process

Figure 2. Bar plot (a, b, c), and Box plot (d, e, f) of various process
\( gTP \) = True positive
\( gTN \) = True negative
\( gFP \) = False positive
\( gFN \) = False negative

\[
\text{Accuracy} = \frac{(gTP + gTN)}{(gTP + gFP + gFN + gTN)} \quad (20)
\]

\[
\text{Specificity} = \frac{gTN}{(gTN + gFP)} \quad (21)
\]

\[
\text{Sensitivity} = \frac{gTP}{(gTP + gFN)} \quad (22)
\]

**Table 1.** Comparison.

| Procedure               | Accuracy | Specificity | Sensitivity |
|-------------------------|----------|-------------|-------------|
| Sobel                   | 0.87     | 0.97        | 0.20        |
| Prewitt                 | 0.86     | 0.97        | 0.20        |
| Kirch                   | **0.94** | **1.00**    | 0.52        |
| Fuzzy C Mean            | 0.77     | 0.76        | **0.84**    |
| Canny                   | 0.85     | 0.95        | 0.22        |
| Jiang and Mojon et al. [13] | 0.89     | 0.90        | 0.83        |
| Nguyen et al. [14]      | **0.94** | ——          | ——          |
| Perez et al. [15]       | 0.92     | 0.96        | 0.64        |
| Abheek et al. [16]      | **0.94** | 0.99        | 0.77        |

The details flowchart is given in Figure 1 which shows the entire segmentation procedures, where the RGB images are converted in grayscale images, then the masks are being created.

**Figure 3.** Input image, Ground Truth, Masking and other output respectively
The filters are performed. Then morphological operations and filters are used. Finally the segmented output images are compared with the corresponding ground truth images. The results of the computed output are given in the form of bar plot and Box plot in Figure 2 (1 means Sobel, 2 means Prewitt, 3 is Kirsch, 4 is Fuzzy C means and 5 is Canny), where mainly Accuracy, Sensitivity and Specificity are shown. Accuracy of Kirsch filter is the best (94%), Sensitivity is the best when Fuzzy c means algorithm (84%) is applied and finally again Kirsch filter is the best for calculating the Specificity (100%). The pictorial result is shown in Figure 3. The comparison table is given in Table 1 with other methods. The table shows the precise segmentation results with respect to the numeric values.

4. Conclusion and Discussion
The comparative study shows that Kirsch filter gives the maximum accuracy while other methods are also recommendable. From the Box plot it is very clear that, the results of using Fuzzy c means algorithm are not very recommendable as the standard deviation is very high. The accuracy may be enhanced to some extent by using some Learning algorithm, i.e., Deep Learning.

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