Automatic Location of Blood Vessel Bifurcations in Digital Eye Fundus Images

Thanapong Chaichana[1], Zhonghua Sun[2], Mark Barrett-Baxendale[1], Atulya Nagar[1]

[1]Biomechanical Electronics Research Group, Department of Mathematics and Computer Science, Liverpool Hope University, Hope Park, Liverpool, UK
chaicht@hope.ac.uk,barretm@hope.ac.uk,nagara@hope.ac.uk
[2]Department of Medical Radiation Sciences, School of Science, Curtin University, Perth, WA, Australia
z.sun@curtin.edu.au

Abstract. Retinal blood vessels are linked with hypertension and cardiovascular disease. It is generally known that vascular bifurcation is mainly involved in varying blood flow velocity as well as its pressure. This paper presents an efficient method for automatic location of blood vessel bifurcations in digital eye fundus images. The proposed algorithm comprised of three main steps: image enhancement, fuzzy clustering, and searching vascular bifurcation. The purposed algorithm revealed successful detection of bifurcations upon test images. Results showed improved diagnostic accuracy in identifying bifurcations with use of the proposed algorithm and encourage its use for further applications such as image registration, personal identification and pre-clinical scanning of retina diagnosis.

Keywords: Bifurcation, retinal image, fuzzy clustering, imaging algorithm, automatic location, fundus image.

1   Introduction

Bifurcation is a common connection in vascular network, basically a connected form of vascular tree structure in retinal image. Blood vessels within the eye supply the blood to retina. Fundus image is a photograph that captures the base of eyeball and principally provides basic information to characterise human eye condition. The main features in retinal image include blood vessels, optic nerve, macula and bifurcation [1-3]. In addition, many eye diseases do not show any signs and symptoms, and they may be painless with no any change in the vision and it can be noticed until the condition is detected at an advanced stage. Retinal image analysis is an important research context to the development of computer-assisted diagnosis and biomedical imaging analysis due to a large amount of future data storage technology and clinical informatics [4]. It requires pre-clinical scanning software prototype to review fundus images for retina diagnosis that can provide quick information and feedback on retinal main features.

Those details can be used to assist ophthalmologist in term of diagnosis and treatments for reducing time, prevention, and making decision for further planning and or surgery. Retinal images representing healthy and eye disease are shown in Figure 1.
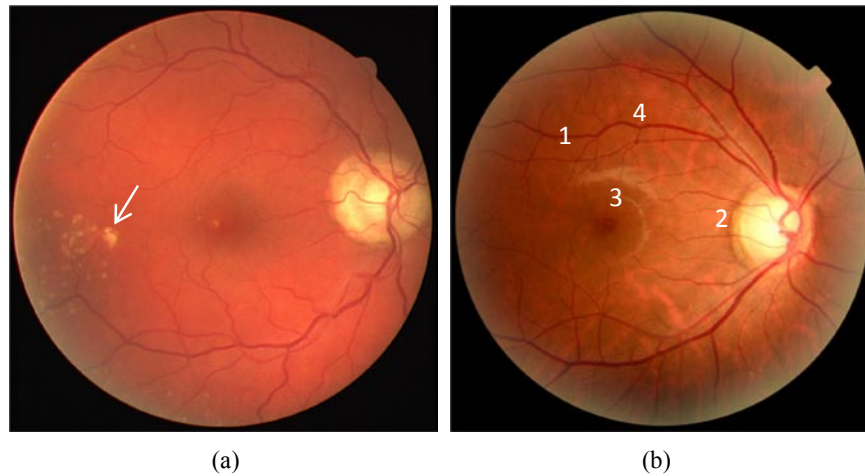

<center>(a)   (b)</center>

Fig. 1. Fundus images: (a) right eye disease [5], arrow points to an area of exudates and this can cause blur/dark spots in the vision; (b) Healthy Eye of a young male adult [6], and main features are: 1) blood vessels, 2) optic nerve, 3) macula and 4) bifurcation

Previous works on identifying vascular bifurcations in fundus images have focused on characterising the vascular junctions as well as vascular crossover-sections. Fatepuria et al. [7] proposed the windows matching techniques to search locations of vascular crossover and bifurcations. They reviewed the accuracy of their proposed algorithm against with an estimation of total numbers of crossovers and bifurcations. The results presented with the test image, have shown 82% of success rate in average.

Calvo et al. [8] presented many windows of crossover and bifurcation patterns to match with those forms in retinal images. They tested their developed algorithm with retinal images obtained from the varpa retinal images for authentication database [9]. Results of identifying crossovers and bifurcations were measured with many classic parameters sensitivity, to determine the specificity, and accuracy. They concluded that their algorithm has shown 93.6% of accuracy in the identified locations. They also addressed that this detection system of crossovers and bifurcations in fundus images is needed to improve on classification technique for more accurate detection of crossover locations.

Azzopardi and Petkov [10] introduced a combination of shifted filter responses (COSFIRE filters) to automatically detect vascular bifurcations in segmented retinal blood vessels from fundus images. They proposed an algorithm by creating trained windows which were used to filter selected bifurcation in different filtering levels and oriented directions, and finally to integrate all filtering results then defined as detected

or undetected location of bifurcations. This algorithm was evaluated as 97.88% of an average precision. The technique is quite in line with "directional filtering in edge detection" proposed by Paplinski [11]. They concluded that COSFIRE filters to automatically search bifurcations can be used to detect any similar bifurcation patterns from trained prototype patterns of bifurcations and in fact the filtered output is a computed weighted geometric denoted of blurred and shifted Gabor filter results.

Waheed et al [12] presented vascular and non-vascular features including blood vessels, bifurcated points, exudate points, luminance, contrast and structure from retinal images for person identification. The biometric system is stable and reliable to identify a person from his/her eye fundus image. Recognition algorithm was proposed in two stages differently, one was using features in retinal image and the other one was using photographic details of retinal image. They concluded that vascular based method is used to improve efficiency of retinal recognition and non-vascular based method is intended to reduce time complexity of recognition system. This biometric system can be improved by integrating retinal pathologies.

Welikala et al [4] introduced automated system to assess image quality of large numbers of fundus images stored in United Kingdom Biobank. They proposed an algorithm to detect retinal images (big data) which are good to clarity conditions across 800 images that are saved in the database, and their assessment condition is paid on structural attributes of segmented vascular, bifurcation and branching trees. Their main aim was to use the imaging quality for future epidemiological studies. However, the segmented results of blood vessels were required to compare with ground truth data (manually hand label blood vessels) for obtaining the classic factors of true and false positive detected. They concluded that the proposed software algorithm was effective in grading retinal images with less time consuming than the manual grading technique, and the algorithm computed completely in around 22h, whilst manual processing completed in 567h. Thus, this software can be used for grading quality of entire retinal images (136,000 images) in UK Biobank and other large retinal datasets.

This work proposes a new searching technique to locate and identify bifurcations in retinal images. The proposed algorithm consisted of three steps which include image enhancement, fuzzy k-median clustering, and searching vascular bifurcation. Figure 1 reveals the flowcode of the current technique.

2   Retinal Imaging Data

Fundus images used in this study were obtained from three sources including the digital retinal images for vessel extraction (DRIVE) database [5], the structured analysis of the retina (STARE) database [13] and the fundus images of Rangsit University (FIRSU) database [6]. The DRIVE dataset contained both healthy and

diseased eye images. These were 40 retinal images which were divided into two groups: training and test datasets, with each set including 20 images equally. The STARE dataset was recorded to have approximately 400 raw images including healthy and diseased conditions. In addition, FIRSU dataset was composed of 10 images of healthy volunteers who have participated in recording digital eye fundus at Robotics Laboratory, Biomedical Engineering, Rangsit University, Thailand, in March 2015. Hence, in this work the test images for automatic locating algorithm were randomly selected from these three sources.
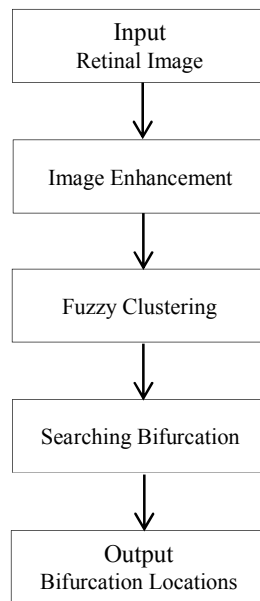
```
┌─────────────────────┐
│       Input         │
│   Retinal Image     │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│  Image Enhancement  │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│  Fuzzy Clustering   │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│ Searching Bifurcation│
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│      Output         │
│ Bifurcation Locations│
└─────────────────────┘
```

Fig. 2. Flowcode of the proposed algorithm

3 Proposed Algorithm

3.1 Image Enhancement

A typical fundus image is recorded in Red, Green and Blue (RGB) colour space by using digital charge-coupled device (CCD) camera attached to the fundus photographic device. Each of RGB compositions is the 2-dimensional arrays of grayscale image; composited G plane of retinal image in Figure 1(b) which can be expressed in matrix form as:

$$F = \begin{bmatrix} f_{0,0} & \cdots & f_{0,N-1} \\ \vdots & \ddots & \vdots \\ f_{M-1,0} & \cdots & f_{M-1,N-1} \end{bmatrix}$$

where F is a 2 dimensional image (G plane of retinal image), matrix F of size $M \times N$. N is shape width (N columns). M is shape height (M rows). f is pixel value of an image.

Hence, Green channel was selected as grayscale image which is G plane representing mostly the luminosity values of the pixels in the median region as shown in our previous study [1]. Then, the blood vessels in retinal image were enhanced by using image convolution approach. A matched filter kernel was designed to convolve with grayscale image and the equation denoted as [1]:

$$h(x,y) = -e^{\left(\frac{-x^2}{2\sigma^2}\right)}$$

where $h(x,y)$ is a 2 dimensional matched filter kernel, matrix of size 16x15. x is column. y is row. σ is standard derivative which was setup value of 2.

An example of retinal image #40_training [5] was processed with image enhancement, and the output is shown in Figure 3.
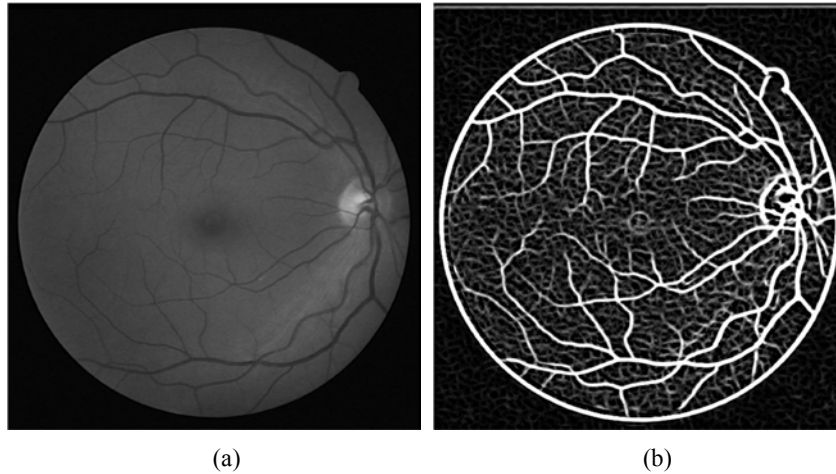

(a) (b)

Fig. 3. Image enhancement: (a) grayscale image (b) matched filter image

3.2 Fuzzy Clustering

In recent years, fuzzy logic has been increasingly used in various applications, such as,

medical imaging and instrumentation, industrial management and data systems, control and process engineering techniques, decision support systems and medical cameras. Medical image segmentation is one of important aspects to process medical imaging data. Fuzzy clustering approach is an efficient method to separate an object of interest in digital image. Since, fuzzy logic has been introduced in the form of logic values to determine the true and false statements, which are the variables between '1' and '0', respectively. In this context, the pixel values of matched filter image in Figure 3(a) ranging from 0-255 was mapped to the Boolean logic, in which pixel values of image ranged from 0-1. Fuzzy c-median clustering was purposed to segment blood vessels in rental image and a simple algorithm was defined as follows [2,3,14]:

Step 1: Let consider matched filter image as a 2 dimensional matrix P

$$P = \begin{bmatrix} p_{0,0} & \cdots & p_{0,N-1} \\ \vdots & \ddots & \vdots \\ p_{M-1,0} & \cdots & p_{M-1,N-1} \end{bmatrix}$$

Step 2: Convert it into 1 dimensional array $P = \{p_1, p_2, p_3, \ldots, p_L\}$. L is size of array that equal to $M \times N$, and the pixel values p were sorted orderly, connected each M row (line array) continuously to L.

Step 3: Calculate a centroid of P by considering median value and histogram of P and a fuzzy partition of C groups.

Step 4: Let consider to cluster P into to c groups. Such that each $p_k \in R^T$, $k = 1,2,3, \ldots, N$ is a feature vector of T consisting objects represented by p_k. A fuzzy c-partition of given dataset is considered as matrix $U = [u_{ij}]$, i $= 1,2,3, \ldots, C$ and $j = 1,2,3, \ldots, N$, and $u_{ij} \in [0,1]$

Step 5: Remap data of each c-partition with its pixel values according to pixel positions in 2-dimensional image.

For instance, the retinal blood vessels in Figure 3(b) are segmented into 2 groups with calculated centroids being 0.2029 and 0.5654, respectively. The images of each fuzzy classified group are shown in Figure 4.
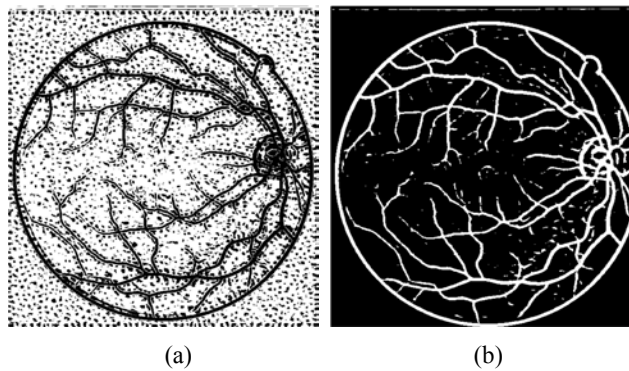

(a)   (b)

Fig. 4. Fuzzy clustering: (a) classified image group a (b) classified image group b

3.3   Searching Vascular Bifurcation

In our preliminary work the vascular bifurcations were estimated including the blood vessel branches with an input and 2 outputs, and vascular crossover with an input and 3 outputs as shown in Figure 5.
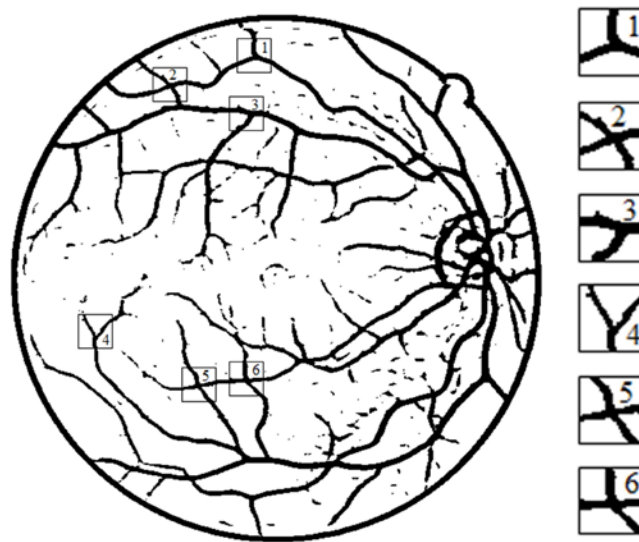

Fig. 5. Bifurcations in retinal image are linked to the boxed images in right column: bifurcations and vascular crossover display no. 1, 3 and 4, and no 2, 5, and 6, respectively.

A simplified algorithm to search bifurcations in retinal images was defined as follows:

Step 1: Convert blood vessels (Figure 4(b)) into binary image which is "0"and "1" are referred to black and white pixels, respectively.
Step 2: Cleaning unconnected and unwanted pixels and then apply morphological thinning approach to erode thickness of blood vessels.
Step 3: Create a 3×3 mask of 9 pixels to scan over each point of pixels in binary image together with collecting cumulative sum in all passing pixel points.
Step 4: Search to scan all points of pixels that have had a total cumulative number of 3-4 and then plot the blue circles to identify bifurcation points.
Step 5: Print the total cumulative numbers.

For example, a segmented blood vessel in Figure 4(b) was processed automatic detection of bifurcations and the results are shown in Figure 6.
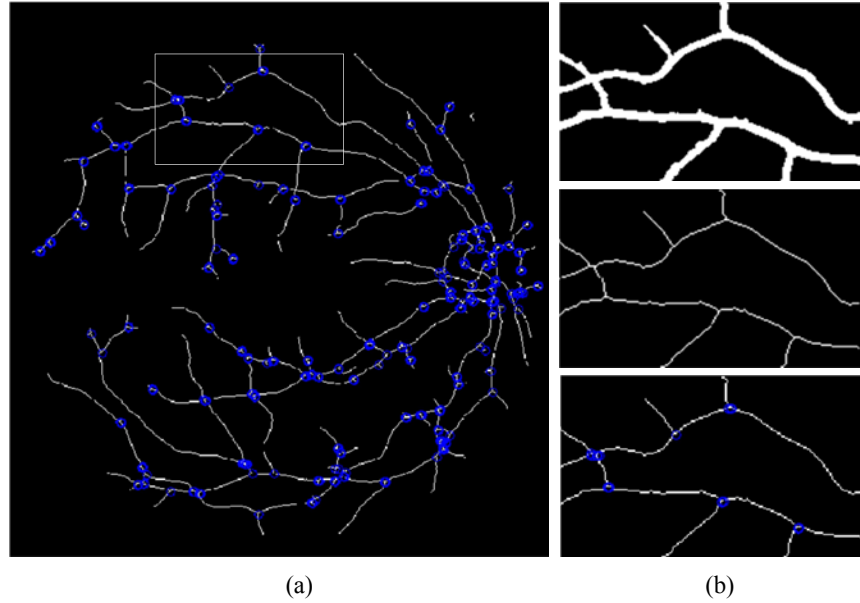
Fig. 6. Identifying bifurcations: (a) blue circles plotted over vascular bifurcations (b) zooming top white rectangle area, images are in column: blood vessels (top), morphological thinning (middle), 7 bifurcations were automatically identified (bottom) and hand calculation was 7 bifurcations.

3 Results

Bifurcation locations in retinal images were performed for computation. The proposed algorithm was coded and written with scripting in Matlab, on a Microsoft Windows 7 32-bit machine, 4 GB of RAM with Intel i5 processor 2.50 GHz CPU. Time computation of all images was estimated to be around 90 seconds.

3.1 Bifurcations in Cropped Retinal Images

The segmented blood vessels in fundus images within the DRIVE database [5] were randomly cropped and used to test with proposed algorithm. The sequential images showing the pathways of algorithm and its performing results are shown in Figure 7.
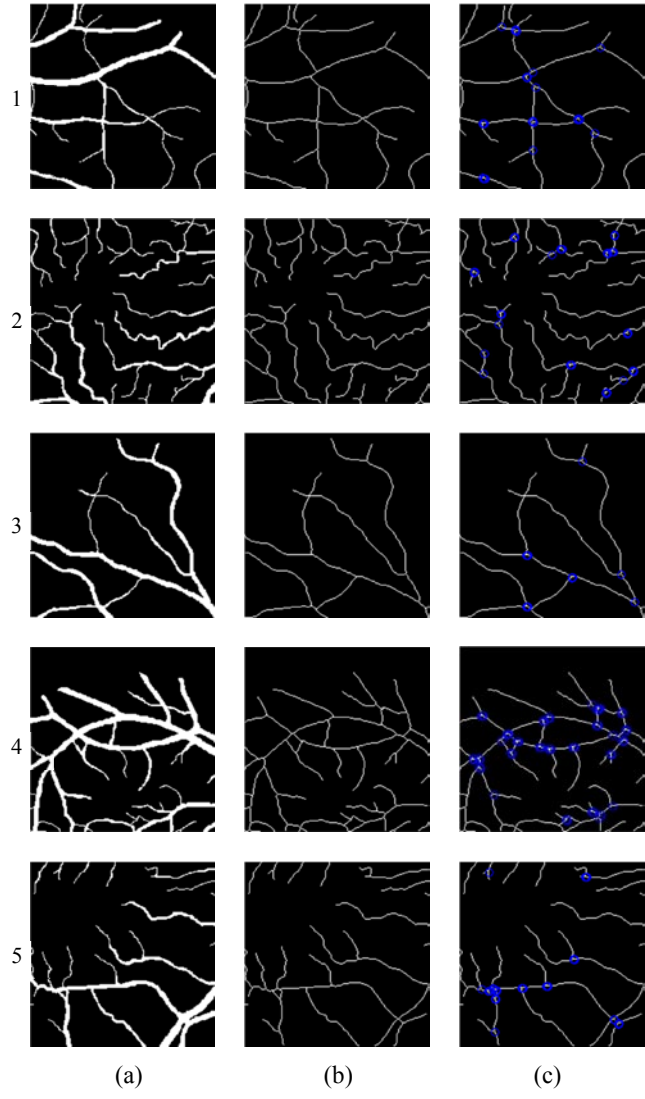
Fig. 7. Automatically locating bifurcations in cropped the segmented blood vessels in fundus images: (a) hand labelled blood vessels, (b) morphological thinning and (c) printed bifurcations.

3.2   Bifurcations in Retinal Images

The digital colour retinal images were randomly chosen within the STARE database [13]. The purposed algorithm was used to locate bifurcations and the pathways of its process and results are shown in Figure 8.
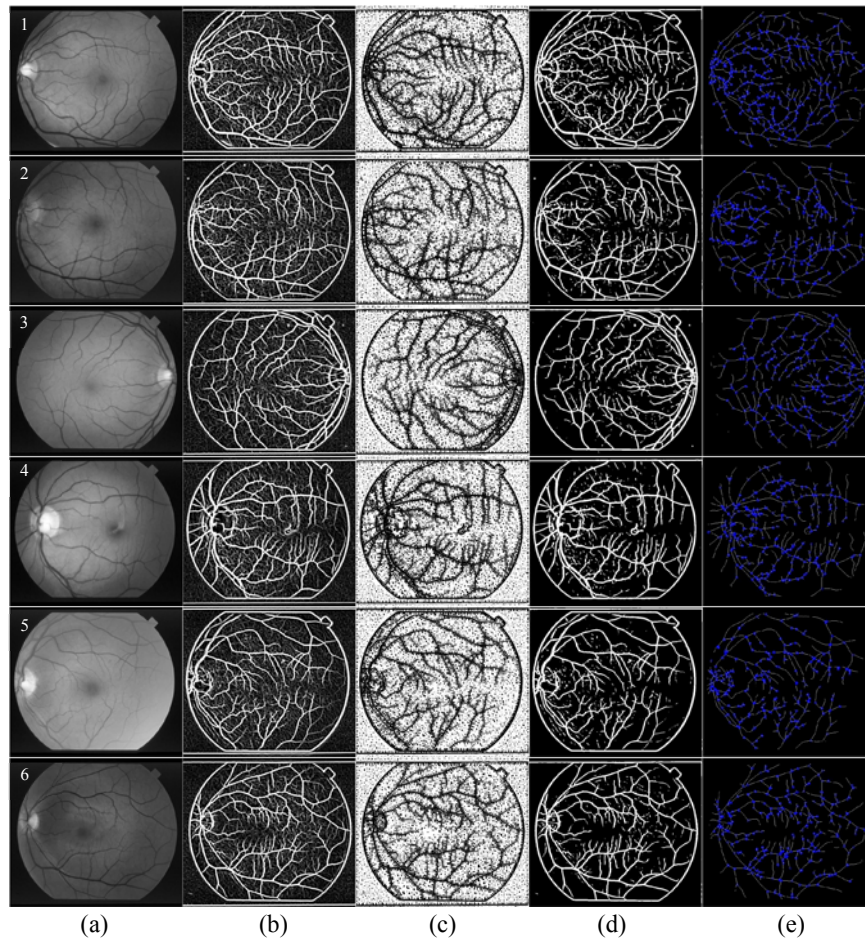

(a)   (b)   (c)   (d)   (e)

Fig. 8. Automatically locating bifurcations in digital colour fundus images: (a) grayscale, (b) matched filter, (c) fuzzy segmentation group one and (d) group two, and (e) printed bifurcations.

4 Conclusion

In this paper, we presented a new algorithm to locate vascular bifurcations in the fundus images. The purposed algorithm has shown enhancement in accuracy and reliability of automatically locating vascular bifurcations. This work was a preliminary study estimating vascular crossover and bifurcation junctions as a bifurcation location. In all cases, we found that there are two bifurcation junctions which were located at vascular crossover, for example, as shown in Figure 5 (in boxed no 2) linked with Figure 6(b). Our results have shown a good agreement with hand calculation and our findings deserve further research in retina diagnosis and comprehensive identification of main features in the fundus images.

Acknowledgements

References

1. Chaichana, T., Yoowattana, S., Sun, Z., Tangjitkusolmun, S., Sookpotharom, S., Sangworasil, M.: Edge detection of the optic disc in retinal images based on identification of a round shape. In: 2008 International Symposium on Communications and Information Technologies, ISCIT 2008, pp. 670-674. IEEE Press, Lao PDR (2008)
2. Sookpotharom, S., Chaichana, T., Pintavirooj, C., Sangworasil, M.: Automatic segmentation of blood vessels in retinal image based on fuzzy k-median clustering. In: 2007 IEEE International Conference on Integration Technology, ICIT'07, pp. 584-588. IEEE Press, Shenzhen, China (2007)
3. Chaichana, T., Wiriyasuttiwong, W., Reepolmaha, S., Pintavirooj, C., Sangworasil, M.: Automatic segmentation of blood vessels in retinal image based on fuzzy k-median clustering. In: 2007 IEEE Fourth International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2007, pp. 144-148. IEEE Press, Haikou, China (2007)
4. Welikala, R.A., Fraz, M.M., Foster, P.J. Whincup, P.H., Rudnicka, A.R., Owen, C.G., Strachan, D.P. Barman, S.A.: Automated retinal image quality assessment on the UK Biobank dataset for epidemiological studies. Comput. Biol. Med. 71, 67-76 (2016)
5. Digital Retinal Images for Vessel Extraction, www.isi.uu.nl/Research/Databases/DRIVE
6. Fundus Images of Rangsit University (FIRSU) database, www.rsu.ac.th
7. Fatepuria, H., Singhania, G., Shah, N., Singh, R., Roy, N.D.: Detection of Crossover and Bifurcation Points on a Retinal Fundus Image by Analyzing Neighbourhood Connectivity of Non-Vascular Regions Around a Junction Point. IJRET. 3, 479-484 (2014)
8. Calvo, D., Ortega, M., Penedo, M.G., Rouco, J.: Automatic detection and characterisation of retinal vessel tree bifurcations and crossovers in eye fundus images. Comput. Methods. Programs. Biomed. 103, 28-38 (2011)
9. Retinal Images for Authentication Database, www.varpa.es/varia.html
10. Azzopardi, G., Petkov, N.: Automatic detection of vascular bifurcations in segmented retinal images using trainable COSFIRE filters. Pattern. Recogn. Lett. 34, 922-933 (2013)
11. Paplinski, A.: Directional Filtering in Edge Detection. IEEE Trans. Image. Process. 7,

611-615 (1998)

12. Waheed, Z., Akram, M.U., Waheed, A., Khan, M.A., Shaukat, A., Ishaq, M.: Person identification using vascular and non-vascular retinal features. Comput. Electr. Eng. 1-13 (2016) In press

13. STructured Analysis of the Retina Project, http://cecas.clemson.edu/~ahoover/stare

14. Sookpotharom, S., Chaichana, T., Pintavirooj, C., Sangworasil, M.: Segmentation of magnetic resonance images using discrete curve evolution and fuzzy clustering. In: 2007 IEEE International Conference on Integration Technology, ICIT'07, pp. 697-700. IEEE Press, Shenzhen, China (2007)