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Supervised Retinal Vessel Segmentation Based Average Filter and Iterative Self Organizing Data Analysis Technique

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Retinal fundus is the inner surface of the eye associated with the lens. The identi¯cation of disease needs some parts of retinal fundus, such as blood vessel. Blood vessels are part of circulation system which functions to supply blood to retina area. This research proposed a method for segmentation of blood vessel in retinal image with Average Filter and Iterative SelfOrganizing Data Analysis (ISODATA) Technique. The ¯rst step with the input image changed to Gamma Correction, increasing contrast with Contrast Limited Adaptive Histogram Equalization (CLAHE), the ¯ltering process with Average Filter. The segmentation is used for ISODATA. Region of Interest was applied to take the center of a vessel object and remove the background. In the ¯nal stage, the process of noise reduction and removal of small pixel values with Median Filter and Closing Morphology. Datasets used in this research were DRIVE and STARE. The average result was obtained for STARE dataset with an accuracy of 94.41%, Sensitivity of 55.57%, Speci¯cation of 98.31%, F1 Score of 64.81% while for the DRIVE dataset with accuracy of 94.78%, Sensitivity of 43.46%, Speci¯cation of 99.81%, and F1 Score of 59.39%.

Keywords: Retinal fundus; average ¯lter; CLAHE; closing morphology, ISODATA.

1. Introduction

An important organ in human body to see is eye. A mark of a person su®ering from eye disease is that there is a change in the retinal image vessels. Blood vessels need to be structured to diagnose various disease because they contain a lot of important information.[1] Researchers also generally use images of the retina to conduct early detection of retinal disease.

Retinal fundus is the interior surface of the eye opposite the lens. Identi¯cation to analyze a disease requires several parts of the retinal fundus, such as the retinal blood

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vessels. The most important part of the human visual system is the retinal blood vessel[2] because the width and curve of the blood vessels of the retina can be a symptom of many diseases. Some retinal diseases can be identi¯ed from several images by the changes shown in the retinal veins.[3] Blood vessels are responsible for supplying blood to all parts of the retina.[4] Segmentation process of blood vessel in retinal image generates useful information for medical ¯eld to identify abnormalities in the blood vessels of the eye. Information about blood vessels in retinal images can be used to assess the severity of the disease or as part of the automatic diagnosis of diseases.[5] Thus, retinal blood vessel segmentation assists in detecting changes and characterizing the presence of a disease.[3]

The most widely used techniques are mainly k-means-based methods, which are easy to use, and obtained results are fairly understandable. Nevertheless, these methods are too static in a particular point of view; at the beginning, we have to specify the number of expected clusters and the algorithm is then responsible to ¯nd them in the data set. There are two alternatives to solve such problem. First, we can do multiple computations with varying number of expected clusters. Such an approach is admissible only in situations where input data set is not to extensive; on large data, it will be very time consuming. Moreover, the decision what partitioning is appropriate is then based on a subjective estimation. Second solution is in adaptation of the algorithm where it will be allowed to split and/or merge clusters according to some prede¯ned condition. Usually, clusters split if the inter-cluster variability increases over some threshold and merged if the typical points of neighboring clusters are near enough. We can also ignore insu±ciently numerous clusters. The second solution was used for example in algorithms like Iterative Self-Organizing Data Analysis (ISODATA).

This research developed a method for segmentation of blood vessel in retinal images. Retinal images will be processed with several image processing methods such as Average Filter and ISODATA. Average ¯lter combined in the pre-processing stage can eliminate noise. Noise removal is done automatically with this ¯lter using a convolution window. This ¯lter will reduce the signal frequency component to be higher and smoother so that the object becomes clearer. The new technique in the segmentation method that combines automated techniques namely average ¯lter at the pre-processing stage, ISODATA at the segmentation stage, and morphological operations at the post-processing stage produce higher accuracy. This process is expected to be an alternative solution to determine the presence of abnormalities in blood vessels in the retinal image which is an early sign of a disease.

2. Related Work

Some researchers have been conducted researches to carry out test regarding segmentation of retinal vein images. This study[6] proposed a blood vessel segmentation with graphs. The technique used was pre-processing with mean ¯lter steps, convolution with Gauss Kernel, shade correction, and Top-Hat transformation.

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However, it still showed less than optimal results because visual inspection still detects some wrong images. Dada[7] used the Primal Dual Asynchronous Particle Swarm Optimization method, but fails to detect thin vessels and there were still some images that are not involved. Son et al.[8] also failed to detect very thin vessels with a range of 1 pixel.

In the research of Ref. 9 who conducted trial in two datasets which were DRIVE and STARE generated a relatively low sensitivity value of 70%. Similar studies were conducted by Ref. 10 with an average sensitivity of 72.05% and an accuracy of 94.79%. However, in the process of removing false positives toward the background, there were still many vessels that had been removed as well. Research[11] with blood vessel segmentation used Local Coarse. Although this method correctly estimated the diameter of the vessel, the local segmentation step of this algorithm led to measurement of excessive diameter. The method proposed by Sazak et al.[12] had limitations that showed the structure of the vessels that are clumped and sensitive to noise such as susceptible to spots, salt, and pepper.

3. Proposed Method

In this research, researcher proposed segmentation method using Average Filter and ISODATA. The ¯rst step was converting the original image to Gamma Correction and then Contrast Limited Adaptive Histogram Equalization (CLAHE) which aimed to improve the quality of the retinal image. Furthermore, the ¯ltering used Average Filter to eliminate noise and smooth the image. In the next step, the blood vessels were segmented using the Iterative ISODATA method and the last step taken was applying the Region of Interest (ROI) method, Median Filter, and Morphological Operations. This research used 40 retinal image data each from the STructured Analysis of the Retina (STARE) dataset and Digital Retinal Images for Vessel Extraction (DRIVE). The °ow chart of the proposed research can be seen in Fig. 1.

3.1. Pre-processing

Image color in fundus usually generates some poor lighting and noise variations. Thus, pre-processing was applied to overcome the bad images and produce good images in the segmentation process. Preprocessing often expanded dark regions like the blood vessels in the initial image.[13] The following are some pre-processing steps.

3.1.1. Gamma correction

The values of intensity were adjusted using gamma correction. Before making contrast enhancements in the image, it is important to apply simple gray level transformation.[14] The formula used in gamma correction[15] is given as follows:

$$I_{out} = A I_{in}; \quad (1)$$

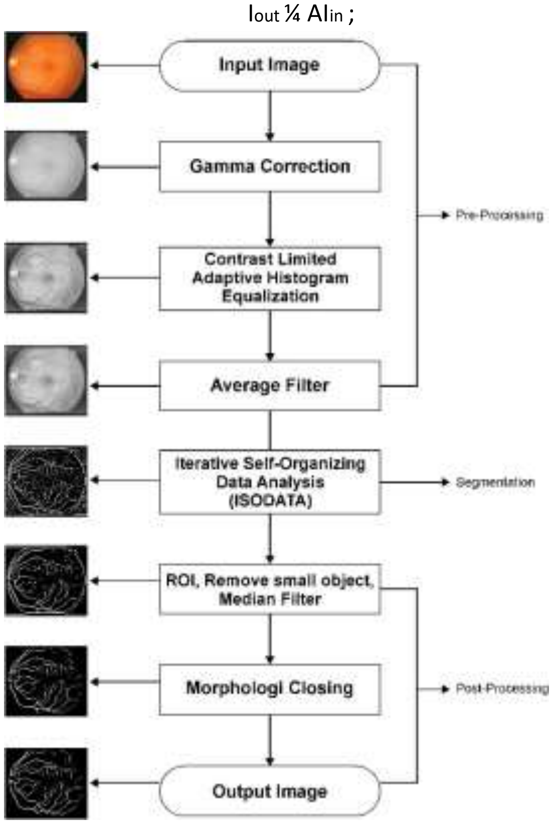

Fig. 1. Block diagram of the proposed method.

where I_{out} is an output image, I_{in} is an input image, A is a constant, and de¯nes the properties of gamma curves.

3.1.2. CLAHE

CLAHE is the spatial domain approach often used to improve contrast.[16,17] The enhancement technique is commonly used in the processing of biomedical images and can render essential sections more easily noticeable.[18] The gray level math operation changed to the CLAHE method with a uniform distribution[19] can be given as follows:

$$g = [g_{max} - g_{min}]P(f) + g_{min}. \qquad (2)$$

3.1.3. Average filter

Basically, filter is a method to eliminate noise in digital images or images. Linear spatial filter is a filter that works by means of correlation or convolution. It is a linear type filter, which smoothes the image's signal.[20] This automatically determines the level of smoothing filter, which is the size of the convolution window in accordance with the value of radiation accumulation received by the smoothed pixels from

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adjacent pixels.[21] The proposed methodology starts with smoothing the input image which results from increasing contrast using an average filter with a 16×16 convolution window. Therefore, the refinement is low intensity to avoid losing important details of the structure. This filter is able to reduces the higher frequency components and generate a signal. Furthermore, shade correction is used which aims to eliminate variations in the background of the image so that the front object to be used is more clearly visible. The shade correction algorithm reduces the intensity of the original image and the average image. The average filter is shown in Ref. 20 in which the variable L is the order of the average filter in Eq. (3).

$$Y[n] = \frac{1}{L}\sum_{k=0}^{L-1} X[n-k]. \quad (3)$$

3.2. Blood vessel segmentation

In segmentation, method which would be used is ISODATA. ISODATA has been widely used in various image processing, namely segmentation. ISODATA algorithm is a grouping of algorithms, in which number of groups has an iteration process working automatically. This algorithm is also flexible because it can combine clusters if the distance value is less than the specified value. The ISODATA method combines several rule-of-thumb procedures in the algorithm for iterative processes.[22] In the ISODATA algorithm, the number of clusters is determined at an early stage and if the iteration process still occurs, the number of clusters cannot be changed. If the iteration stops, ISODATA grouping characteristics and clusters will be divided separately.[23] The steps of ISODATA Algorithm are as follows:

(1) Chose k value = K0, then randomly move data to the cluster.

(2) Calculate the centroid of a cluster by valuing vector values. (3) Determine the cluster data points from the average value using Eq. (4).

$$x \in \omega_i \text{ if } d(x;m_i) = \min\{d(x;m_i);\ldots;d(x;m_k)\}; \quad (4)$$

in which x is the data and m is the center of the cluster.

(4) Remove cluster which only has some members if $n_j < n_{min}$ removes clusters and moves to other groups.

(5) Update centroids on clusters $\omega_j (j = 1;\ldots;K)$ with Eq. (5).

$$m_j = \frac{1}{n_j} \sum_{x \in \omega_j} X: \quad (5)$$

(6) If k value $K \; K_0/2$, then proceed to step 7 to separate clusters and if $K \; 2K_0$, then the process continues to step 8 to merge clusters.

(7) Divide each cluster $\omega_j (j = 1;\ldots;K)$ and calculate greatest covariance value with Eq. (6).

$$^2 = \max\{^2_1;\ldots;^2_N\}; \quad \text{if } ^2_m > ^2_{max} \text{ and } n_j > 2n_{min}: \quad (6)$$

Then it will divide into two new cluster centers.

$$m_{j1} = m_j + m \quad \text{and } m_{j2} = m_j \; m:$$

(8) Use Euclidean Distance to calculate each centroid if the result of d_B is equal to $d_B(\omega_i \omega_j) < d_{min}$, then it will combine the two clusters with Eq. (7).

$$m_i = \frac{1}{n_1 + n_j}[n_i m_i + n_j m_j]: \quad (7)$$

(9) If the maximum iteration has not been met, the process will repeat to step 2. And if the maximum iteration has been ful¯lled, the iteration process will automatically stop.

3.3. Post-processing

After conducting segmentation of blood vessel, the last step to do is post-processing. At this stage, there are several processes conducted to eliminate the noise in the vessels in order to obtain good results. The ¯rst step is the ROI process. ROI is the center of the original image in a circle by removing the background. Background deletion is done to focus on removing blood vessels by changing the entire black retina apart from the white retina.[24] The next step is the process of smoothing and reducing noise in the image. This ¯ltering approach reduces various forms of noise to create speci¯c edges in the picture.[25] The last step in post-processing is the output of blood vessel segmentation results, previously carried out a morphology cleaning process to get better results. The method applied closure morphological operation which is useful for smoothing contours and removing small pixels.

4. Result and Discussion

This research used MATLAB R2018b Software as tool which would be used to design method with computer equipment speci¯cations used are the Intel^r Core™ i5-7200U CPU @ 2.50GHz, 2.71GHz, 4.00GB Memory, System type 64-bit Operating System, x64-based processor. The dataset that would be used was Digital Retina Image for Vessel Extraction (DRIVE) and Structured Analysis of the Retina (STARE), where this study uses 20 retinal image data. The general de¯nition of retinal image processing was taken from one of the retinal images to obtain the e®ect of blood vessel segmentation in the following.

The following is the process of blood vessel segmentation in Fig. 2. Section (a) is the original image that would be used as input then converted to a grayscale with the Gamma Correction approach in section (b). This experiment used a gamma value of 0.3. Gamma correction was needed in adjusting the contrast to get the desired intensity value which impacts the next process of CLAHE. CLAHE is a process of increasing contrast that makes important parts appear more clearly like blood vessels

12:55:16pm

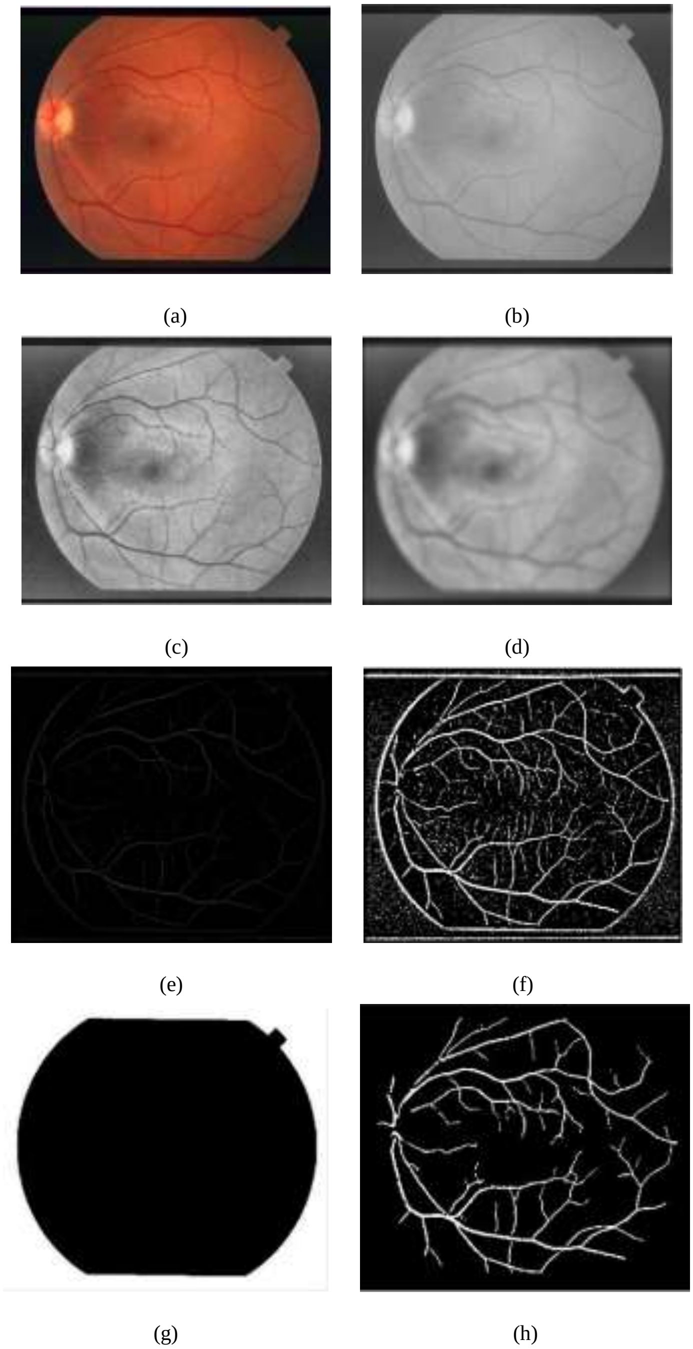
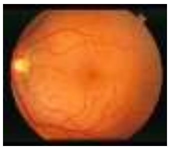
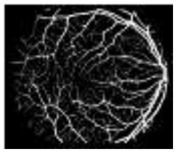

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

Fig. 2. Segmentation process: (a) original image, (b) gamma correction, (c) CLAHE, (d) average ¯lter, (e) shade correction, (f) ISODATA threshold, (g) ROI, and (h) ¯nal segmentation results.

Table 1. Comparison of proposed method segmentation result with ground truth STARE.

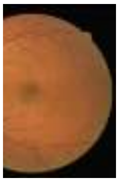
No.	File Name	Image	Ground Truth		Proposed Method
			Adam Hoover	Valentina Kouznetsova	
1.	Im07.ppm				
2.	Im09.ppm				
3.	Im11.ppm				
4.	Im13.ppm				

in section (c). Then the filtering process was carried out, the purpose of this filtering was to smooth and eliminate noise in the image by using the Average Filter in section (d). To remove background variations in making the object of the blood vessel more clearly visible, the shade correction process was used by subtracting the original image and the average filter in section (e). Then for the process of segmenting blood vessels in retinal images used ISODATA in section (f). In the final stage, the ROI was applied to take the center of the object of the vessel by separating the entire black retina and separate it from the white retina in section (g). Furthermore, the process of eliminating noise and small pixel values that still existed in the image using a median filter followed by morphological closure operations to obtain the final result of blood vessel segmentation in section (h).

Some results of image process for blood vessel segmentation with method proposed can be seen in Tables 1 and 2. This uses the DRIVE and STARE dataset which will compare segmentation results with each Ground Truth dataset.

Measuring performance parameter result from the research is an important thing to find out how well the results of research have been conducted by matching based on the retinal Ground Truth. The parameters used to get the results of accuracy, Technique

Table 2. Comparison of proposed method segmentation result with ground truth DRIVE.

No.	File Name	Image	Ground Truth	Proposed Method
1	01. tif			
2	02. tif			
3	05. tif			
4	19. tif			

sensitivity, speci¯cations, and F1 score in Confusion Matrix, as follows:

Accuracy ¼ TP þ FNþþTNTN þ FP ; TP

$$\text{Sensitivity} = \frac{TP}{TP + FN};$$

$$\text{Spesification} = \frac{TP}{TP + FP};$$

$$\text{F1 Score} = 2\left(\frac{\frac{TP}{TP+FP} \cdot \frac{TP}{TP+FN}}{\frac{TP}{TP+FP} + \frac{TP}{TP+FN}}\right);$$

where

TP = True Positive, the number of positive images that match based on the dataset correctly by the system.
TN = True Negative, the number of negative images that match based on the dataset correctly by the system.

Table 3. Calculating for accuracy, sensitivity, speci¯city, and F1 score with STARE and DRIVE dataset.

File Name	STARE				File Name	DRIVE			
	Acc	Se	Sp	F1		Acc	Se	Sp	F1
im01.ppm	89.49	45.29	95.49	50.75	01. tif	95.13	51.70	99.58	66.38
im02.ppm	90.94	41.19	96.41	47.37	02. tif	94.47	47.24	99.91	63.81
im03.ppm	89.40	44.06	94.80	46.93	03. tif	94.22	44.89	99.79	61.19
im04.ppm	94.69	41.30	99.34	55.50	04. tif	94.57	41.88	99.94	58.80
im05.ppm	93.33	49.84	98.41	60.97	05. tif	94.86	47.17	99.86	63.53
im06.ppm	93.66	58.70	97.29	63.55	06. tif	93.77	36.72	99.95	53.54
im07.ppm	95.45	66.75	98.44	73.46	07. tif	94.73	44.04	99.89	60.69
im08.ppm	95.98	66.64	98.74	74.05	08. tif	94.40	37.66	99.84	54.05

im09.ppm	95.71	64.67	98.77	73.04	09. tif	94.24	29.53	99.97	45.46
im10.ppm	92.35	52.52	97.09	59.36	10. tif	95.12	45.81	99.70	61.48
im11.ppm	96.38	63.20	99.21	73.28	11. tif	94.93	45.83	99.84	62.18
im12.ppm	96.70	69.40	99.22	78.04	12. tif	94.79	42.62	99.82	59.01
im13.ppm	95.49	64.02	98.93	73.68	13. tif	94.06	41.26	99.86	57.90
im14.ppm	95.36	62.58	98.99	72.90	14. tif	95.26	46.21	99.72	61.91
im15.ppm	94.96	59.85	98.76	69.86	15. tif	96.01	55.33	99.41	68.14
im16.ppm	93.56	50.45	98.98	63.55	16. tif	94.56	41.85	99.87	58.47
im17.ppm	95.88	60.67	99.52	73.42	17. tif	93.83	28.10	99.94	43.63
im18.ppm	97.08	52.45	99.63	66.01	18. tif	95.09	41.63	99.81	57.88
im19.ppm	96.72	48.22	99.27	59.51	19. tif	96.17	57.48	99.77	71.86
im20.ppm	95.09	49.63	98.88	60.89	20. tif	95.31	42.22	99.70	57.89
Average	94.41	55.57	98.31	64.81	Average	94.78	43.46	98.81	59.39

FN = False Negative, the number of negative images but matched based on the wrong dataset by the system.

FP = Positive False, the number of positive images but matched based on the wrong dataset by the system.

Based on the parameters of the formula, the results of measurements of accuracy, sensitivity, speci¯cations, and F1 score results are obtained from the STARE and DRIVE datasets in Table 3.

The result of parameter measurement was taken from 40 retinal images. Each retina consists of 20 STARE datasets and 20 DRIVE datasets. Based on the results in Table 3, the values obtained by each of the parameters of blood vessel segmentation using Average Filters and ISODATA are relatively high when compared with some studies that have been conducted. Table 4 shows a comparison of the proposed method with several studies that have been carried.

Based on the result of Table 5, other researches also used the same dataset such as STARE and DRIVE with a dataset of 40 images. The results of calculations using the parameters of accuracy, sensitivity, and speci¯cations are obtained from an average of 20 images tested. It can be seen in Table 5 that the proposed method has advantages over previous studies, especially in accuracy and speci¯cations. In research by Azzopardi et al.[26] with the STARE dataset, the accuracy was higher when

Table 4. Comparison of previous studies with proposed method.

Method	Accuracy (%)	Sensitivity (%)	Speci¯city (%)
STARE Dada[7]			
Neto et al.[11]	88.94	83.44	94.43
Azzopardi et al.[26]	94.97	77.16	97.01
Proposed method	94.41	55.57	98.31
DRIVE			
Dada[7]	92.43	57.21	98.34
Neto et al.[11]	87.18	78.06	96.29
Azzopardi et al.[26]	94.42	76.55	97.04
Proposed method	94.78	43.46	99.81

compared with the proposed method, but the proposed method has advantages in the measurement results of the parameter speci¯cations. Therefore, the results of this research can be compared with previous researches.

5. Conclusion

In this research, segmentation of retinal blood vessel uses ISODATA in which there are several methods combined. Stages of the process carried out to get the performance results of accuracy with color changes, image enhancement, ¯ltering, noise removal, etc. This research uses the STARE dataset and to measure the ability of research performance using the parameters of accuracy, sensitivity, and speci¯cations. Thus, the proposed method obtains an average measurement result of STARE dataset parameters with an accuracy of 94.41, Sensitivity of 55.57%, Speci¯cation of 98.31%, and F1 score of 64.81% while for DRIVE datasets obtained Accuracy of 94.78%, Sensitivity of 43.46%, Speci¯cations of 99.81%, and F1 Score of 59.39%. Evaluation of performance of method proposed depicts that ISODATA method °exibly can determine initial cluster. Thus, it can avoid local optima and generates better result compared to previous method, either in accuracy and speci¯cations. Therefore, this method is e®ective to use in processing image for segmentation. Although the sensitivity value is smaller than the previous method due to the presence of false positives detected. Also, in the STARE dataset, there are smaller results than the previous method in calculating the accuracy parameter. However, the speci¯cation value is higher than before. In image processing, the value of the measurement parameter will be in°uenced by the process value before and after the segmentation image. Therefore, for further research, the sensitivity value will be increased and reduce false positives in order not to be detected.

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References

1. N. P. Singh and R. Srivastava, Retinal blood vessels segmentation by using Gumbelprobability distribution function based matched ¯lter, Comput. Methods Programs Biomed. 129 (2016) 40–50.
2. U. Ozkava, S. Ozturk, B. Akdemir and L. Sev¯, An e±cient retinal blood vessel segmentation using morphological operations, in Int. Symp. Multidiscip. Stud. Innov. Technol. Proc. (Ankara, Turkey, 2018), pp. 1–7.
3. S. Kaur, Optimized retinal blood vessel segmentation technique for detection of diabeticretinopathy, Int. J. Adv. Res. Comput. Sci. 8 (2017) 508–512.
4. D. S. Raja and S. Vasuki, Automatic detection of blood vessels in retinal images fordiabetic retinopathy diagnosis, Comput. Math. Methods Med. 2015 (2015) 8–12.
5. T. Chanwimaluang and G. Fan, An e±cient blood vessel detection algorithm for retinalimages, in Proc. 2003 Int. Symp. Circuits and Systems, 2003. ISCAS '03, Vol. 2 (Bangkok, Thailand, 2003), pp. 21–24.
6. P. R. Wankhede and K. B. Khanchandani, Retinal blood vessel segmentation usinggraph cut analysis, in Int. Conf. Ind. Instrum. Control. ICIC (Pune, India, 2015), pp. 1429–1432.
7. E. G. Dada, Retinal vessel segmentation based on primal-dual asynchronous particleswarm optimization (pdAPSO) algorithm, Arid Zo. J. Eng. Technol. Environ. 13 (2017) 229–237.

8. J. Son, S. J. Park and K. H. Jung, Retinal vessel segmentation in fundoscopic images withgenerative adversarial networks, Comput. Vis. Pattern Recogn. 1706 (2017) 1–9.
9. G. Chen, M. Chen, J. Li and E. Zhang, Retina image vessel segmentation using a hybridCGLI level set method, Biomed Res. Int. 2017 (2017) 1–11.
10. S. A. A. Shah, T. B. Tang, I. Faye and A. Laude, Blood vessel segmentation in colorfundus images based on regional and Hessian features, Graefes Arch. Clin. Exp. Ophthalmol. 255 (2017) 1525–1533.
11. L. C. Neto, G. L. B. Ramalho, R. J. F. S. Neto, R. M. S. Veras and F. N. S. Medeiros, Anunsupervised coarse-to-¯ne algorithm for blood vessel segmentation in fundus images, Expert Syst. Appl. 78 (2017) 182–192.
12. C. Sazak, C. J. Nelson and B. Obara, The multiscale bowler-hat transform for blood vesselenhancement in retinal images, Pattern Recognit. 88 (2019) 739–750.
13. A. Budai, G. Michelson and J. Hornegger, Multiscale blood vessel segmentation in retinalfundus images, in CEUR Workshop Proc., Vol. 574 (Almaty, Kazakhstan, 2010), pp. 261– 265.
14. P. M. Patel and S. M. Shah, Comparitive analysis for pre-processing of images and videosusing histogram equalization methodology and gamma correction method, Int. Res. J. Eng. Technol. 4 (2017) 3160–3164.

15. R. Mumtaz, M. Hussain, S. Sarwar, K. Khan, S. Mumtaz and M. Mumtaz, Automaticdetection of retinal hemorrhages by exploiting image processing techniques for screening retinal diseases in diabetic patients, Int. J. Diabetes Dev. Ctries. 38 (2018) 80–87.
16. K. Narasimhan, C. Sudarshan and R. Nagarajan, A comparison of contrast enhancementtechniques in poor illuminated gray level and color images, Int. J. Comput. Appl. 25 (2011) 17–25.
17. M. S. Hitam, E. A. Awalludin, J. W. Yussof and Z. Bachok, Mixture contrast limitedadaptive histogram equalization for underwater image enhancement, in Int. Conf. Comput. Appl. Technol. ICCAT 2013 (Sousse, Tunisia, 2013), pp. 1–5.
18. B. Wu, W. Zhu, F. Shi, S. Zhu and X. Chen, Automatic detection of microaneurysms inretinal fundus images, Comput. Med. Imaging Graph 55 (2017) 106–112.
19. B. B. Singh and S. Patel, E±cient medical image enhancement using CLAHE enhancement and wavelet fusion, Int. J. Comput. Appl. 167 (2017) 1–5.
20. D. Montenegro and J. Gonzalez, Average Filtering: Theory, Design and Implementation (Nova Science Publisher, New York, 2016).

21. A. F. De Araujo, C. E. Constantinou and J. M. R. S. Tavares, Smoothing of ultrasoundimages using a new selective average ¯lter, Expert Syst. Appl. 60 (2016) 96–106.
22. M. Li, S. Han and J. Shi, An enhanced ISODATA algorithm for recognizing multipleelectric appliances from the aggregated power consumption dataset, Energy Build. 140 (2017) 305–316.
23. E. F. Sirat, B. D. Setiawan and F. Ramdani, Comparative analysis of k-means and isodata algorithms for clustering of ¯re point data in Sumatra region, in 2018 4th Int. Symp. Geoinformatics, ISyG 2018 (Malang, Indonesia, 2019), pp. 1–6.
24. Erwin and T. Kiyatmoko, Retinal vessel extraction using dynamic threshold and enhancement image ¯lter from retina fundus, J. Inf. Syst. Telecommun. 6 (2018) 189–196.
25. P. B. Chanda and S. Sarkar, Automatic identi¯cation of blood vessels, exaudates andabnormalities in retinal images for diabetic retinopathy analysis, in Proc. Int. Conf. Advancements in Computing & Management (ICACM) 2019 (Jaipur, India, 2019), pp. 1–9.
26. G. Azzopardi, N. Strisciuglio, M. Vento and N. Petkov, Trainable COSFIRE ¯lters forvessel delineation with application to retinal images, Med. Image Anal. 19 (2015) 46–57.