Research Article

Analysis of thick and thin vessel pixel clustering for retinal blood vessel image segmentation

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ABSTRACT

Aim: In this work, we revealed that digital image processing is an actual topic at present and it is widely used in various fields of medicine, including diagnosis of the eye fundus. **Methods:** We carried out the analysis of the correlation between results of the segmentation and the selected number of classes. **Results:** An analysis of the dependence of the blood vessel segmentation results on the image of the eye fundus from various partitions to pixel classes corresponding to thick and thin vessels obtained by k-means clustering was made. **Conclusion:** Using the openly accessible database of eye fundus images DRIVE, we fulfilled the computational experiments which results demonstrated the effectiveness of the analyzed method of retinal blood vessels segmentation based on the separate thick and thin vessel pixel clusterings.

KEY WORDS: Clustering, DRIVE database, Eye fundus, K-means method, Matlab, Retinal blood vessels, Segmentation

INTRODUCTION

Now for the diagnosis of various diseases, the health professionals often use the results of the eye fundus circulatory system's vessel state analysis. In many cases, eye fundus images are used for the diagnosis of diseases.[1]

In the images of the eye fundus, the following elements are usually set off [Figure 1]:

- Vascular membrane (consists of arteries and veins of varying thickness),
- Optical disk and optic disk cupping,
- Macula (yellow spot),
- Fovea (central pit).

According to the image of the eye fundus, it is possible to identify and localize:[2] Retinal detachment, retinal hole, neoplasms and damages of the eye fundus pigmentation, micro haemorrhage of the retina and retinal pigmental epithelium, demonstrations of the diabetic retinopathy (retinal affection in diabetes mellitus), including hemorrhages, edema, exudates, thrombosis of the retinal blood vessels, and other pathological changes.

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The analysis of circulatory system vessels of the eye fundus has an important place in most known methods of the eye fundus research because the eye fundus is the only human body part where it is possible to observe the circulatory system directly without surgical intervention. Obviously that manual selection of the vascular system is a rather laborious process taking into consideration the too complicated structure of the vascular tree and often low-contrast and noised images of the eye fundus.[3]

Hence, for eye fundus image analysis, the specialists widely use the computers that improved the quality of diagnostics.[4] Now, the computer analysis is the main tool for medical diagnostic systems. The correct using of computer analysis demands the high image quality[5] because it results strongly depend on the brightness and contrast of the original image of the eye fundus vascular system.

One of the problems affecting the quality of the eye fundus image is the presence of irregular brightness during photography. The example of eye fundus image with irregular brightness is demonstrated in Figure 2.

Irregular brightness in the image may occur due to the structure of the retina. The retina is a spherical surface that is illuminated by a light source located a few centimeters from the pupil. The camera, which is also

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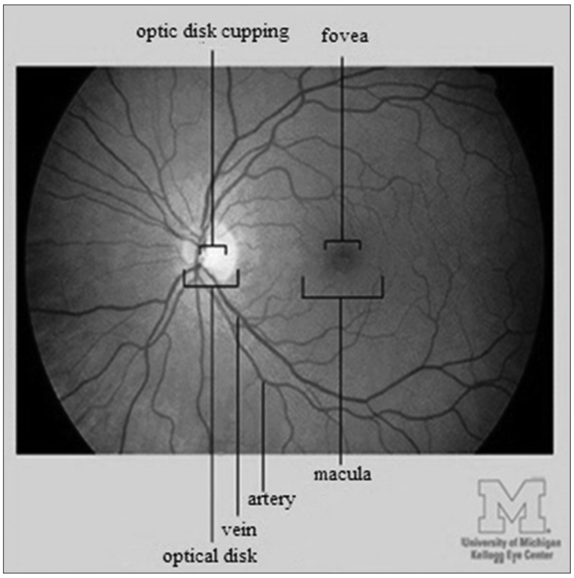

Figure 1: Image of e`ye fundus

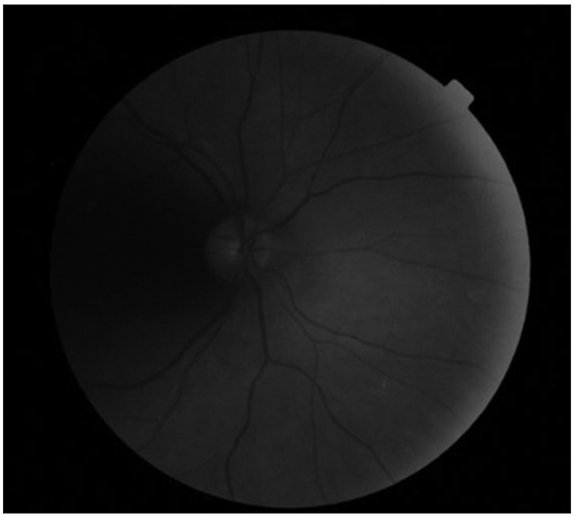

Figure 2: Eye fundus image with irregular brightness

close to the pupil, fixes the light that reflected from the retina. Due to this arrangement of the photography elements relative to each other, the peripheral surface of the retina is poorly illuminated, and this region is darker in the eye fundus images.

Furthermore, a significant problem is the small size of the pupil hole, through which it is necessary not only to photograph the eye fundus but also to evenly and well illuminate it, eliminating the reflections (reflexes) from the surface of the cornea and the crystalline lens. To eliminate the reflexes, one part of the pupil is used to introduce light, and the other is used for imaging.

Despite strictly controlled conditions in which the eye fundus photography is made, the quality of the images is also affected by several factors that depend on the patient and therefore is difficult to control. As a result, irregular brightness and contrast are often observed in the eye fundus images.

Thus, the factors that affect the quality of eye fundus images are as follows:

a. Curved surface of retina. As a result, all parts of the retina cannot be illuminated in the same way;
b. Photography needs mydriatic pupil. Each patient has own level of pupil dilation. Insufficient view of the eye fundus due to incomplete dilation of the pupil leads to a decrease the quality of the image;
c. Unforeseen movements of the patient's eyes. A bright light makes a person unconsciously change the direction of the view;
d. The presence of diseases such as cataract, dimness of the optical media of the eye and many others, and preventing light from entering the retina.

To achieve sufficient illumination in photographing of the eye fundus, gas discharge flash lamps with a flash energy of 100–800 J are used in all modern devices. The short duration of the flash of such lamps excludes the influence of the mobility of the eye and facilitates the photography procedure for the patient. Constant light that is necessary in the process of focusing the apparatus creates by low-voltage incandescent lamps.[6]

However, often, the use of these photography methods of the eye fundus is not enough to obtain an image without artifacts that affect the quality of the image that is why computer preprocessing of images is topical in this case.[7]

BACKGROUND

Features of the Automatic Retinal Vessel Segmentation Methods

The vessel segmentation on the eye fundus images has mostly two directions of the development:

- Eye fundus image segmentation which allows to recognize the vessels of eye fundus circulatory system;
- The vessel tracking.

In most cases, in the development of the vessels segmentation algorithms, the following approaches are used.

Matched Filtering

Matched filtering[8] applies different two-dimensional filters for finding vessel pixels on images. Filter mask corresponds to the target elements of the vessels. Hence, the filter response indicates the presence probability of the required vessels elements.

Modeling of filter mask is based on the following assumptions:

- The vessels can be described by the line segments;
- The vessels size decreases from vessels near to the optical disk to vessel ends;
- The vessel cross-sectional shape is comparable to the Gaussian curve.

The filter mask should be taken quite large, and the filter itself must be applied in several directions, which leads to a significant increase of the calculation's complexity. The kernel of the filter should also correspond to the scale of the vessel to be detected. As a consequence, the filter will not give a clear response to the vessels with a profile having a different scale. Changing the background of the image and the presence of various pathological artifacts also increases the percentage of false filter responses since pathologies can have parameters close to the parameters of the vessels. The border of the optical disc, hemorrhage, and tissue damage can also have characteristics that are peculiar to vessels. The use of an extended structural element can also make it difficult to recognize extremely convoluted vessels. The use of matched filtering is quite effective in combination with other methods of image processing.[8]

Morphological Processing

Morphological processing implies that the vessels consist of interconnected linear segments. Morphological operations are used for the vessels segmentation and the recognition of microaneurysm.[9-11]

In most cases, two widely known morphological operations TopHat transformation[12] and the watershed method[13] are applied during the vessel image segmentation. For using these operation, we assume that the structure of the vessel system can be described by a set of connected line segments.

TopHat transformation allows to emphasize the vessels. This operation is based on the use of opening and closing morphological operations. It allows to estimate the image background. Hence, we can isolate the vessels by removing the image background from the initial image.

The advantages of morphological processing for the identification of certain forms are high speed of operation and resistance to noise.

The main disadvantage of the exclusively morphological methods using is that they do not use information about the profile of the vessels moreover, and in the search for extended structures, the possibility of having convoluted vessels in the image is not taken into account.[14]

Multiscale Analysis

Numerous researches[15] have shown that the vessel cross-sectional shape can be approximately described by Gauss function and also the vessels are comparable to linear 3D-objects those sizes are smoothly decreased. The use of the spatially scale analysis for vessel segmentation is based on the existence of scale-independent vessel information.[16] During the development of a filter for vessel segmentation, we can use the second-order multiscale structures (Hessian matrix). The analysis of the Hessian matrix eigenvalues and eigenvectors allows to find vessels. It allows to define the directions of smallest line segments along the vessel channel. The resulting evaluation of the vessel is calculated using the geometric parameters of the vessel, as well as the eigenvalues and norms of the Frobenius matrix, and verified on images obtained by angiography and 3D magnetic resonance tomography. The multiscale analysis approach showed the ability to a simultaneously rejection of noise and background of image. Many algorithms are based on this approach.

Vessel Tracking

Algorithms (trace) segment the vessel between two given points. This method works at the level of one vessel and not at the level of the vascular system.[17]

The advantage of this approach is the ability to trace thin and discontinuous vessels, which are not detected using other methods. Furthermore, the advantage of vessel tracking is that the trace algorithms require less computations. Given that, all the vessels are connected together in a common vascular system, and the trace algorithm can recognize the entire tree wholly without losing time processing those parts of the image that do not contain the vessels. Thus, unlike other approaches, trace is able to provide information on the structure of the vascular tree: Bifurcations and connections of some branches.

However, this approach requires knowledge of the initial points, and sometimes, the final ones belong to the detected vessel, and this makes it difficult to apply this approach in fully automatic systems. Furthermore, the situation of crossing and branching of blood vessels causes an additional difficulty.

METHODS

Developed method of retinal blood vessel segmentation based on contrast-limited adaptive histogram equalization, morphological filtering, k-means clustering, and matched filtering was described in the work.[18]

The main steps of this algorithm of the retinal blood vessels segmentation are shown in the block diagram in Figure 3.

We analyze various variants of clustering of pixels of the eye fundus image for the purpose of the blood vessels segmentation based on developed method.

We have conducted the preliminary computational experiments which showed the following: While using the values of the eye fundus image pixel brightness for "k" class clustering, the majority of the pixels corresponding to thick blood vessels are included into the senior class S_k. Furthermore, two senior classes S_{k-1} and S_k contain the majority of pixels corresponding to all eye fundus blood vessels.

For segmentation of pixels corresponding to thin blood vessels,[19] clustering of the set of pixels of the previously obtained class S_{k-1} into n classes $\{G_j\}$, j = 1,2,…,n, is performed. In the course of preliminary computational experiments, it was also revealed that, in the senior class G_n, there are most pixels of thin blood vessels.

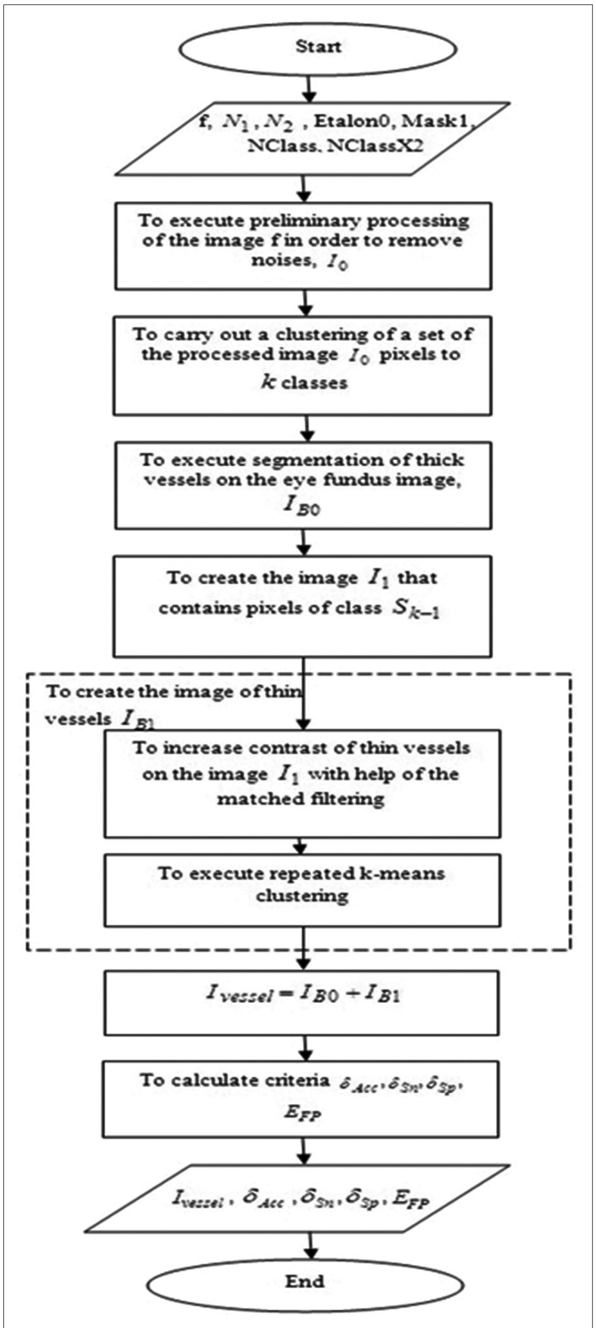

Figure 3: Block diagram of the algorithm of the retinal blood vessel segmentation

EXPERIMENTAL RESULTS

We will research the dependence of the results of vessel segmentation on different values of k and n, which were used in the course of the k-means clustering described above.

To evaluate the efficiency of the developed clustering approach for the purpose of the retinal blood vessels segmentation, it is proposed to use next criteria: The accuracy δ^{kn}_{Acc} (it indicates the overall segmentation performance) and first kind error E^{kn}_{FP}. These criteria are defined as follows:[18,20]

$$\delta^{kn}_{Acc} = (N_{tp} + N_{tn})/(N_{tp} + N_{fp} + N_{tn} + N_{fn}) \quad (1)$$

$$E^{kn}_{FP} = N_{fp}/(N_{tp} + N_{fn}) \quad (2)$$

Where N_{tp} - correctly identified vessel pixels amount (true positive), N_{tn} - correctly identified background pixels amount (true negative), N_{fp} - incorrectly identified vessel pixels amount (false positive), N_{fn} - incorrectly identified background pixels amount (false negative), and - relation of incorrectly identified vessel pixels amount N_{fp} to total pixels amount.

For computational experiments, the initial data were images from database DRIVE of eye fundus images.[21]

The computing experiments were fulfilled for defining the concordance of the pixels belonging to the eye fundus vessels and the pixels included in the senior classes which were received using the k-means clustering method.

For the analysis of the best variants of splitting into classes, it is suggested to use the linear convolution of the criteria, which is defined as follows:

$$\Phi^{kn} = \alpha\delta^{kn}_{Acc} + (1+\alpha)E^{kn}_{FP} \quad (3)$$

Where α = 0.8 - weighting coefficient determining the importance of the criterion (in this case, the accuracy is considered more important than the first kind error).

Table 1 shows the criteria values of the accuracy, the first kind error, and the linear convolution of the criteria of the analyzed method[18] for a different number of classes k for the clustering of thick blood vessels and the number of classes n for the clustering of thin blood vessels.

Table 1: Values of criteria δ_{Acc}, δ_{Sn}, and δ_{Sp} when we used the analyzed method[18]

Image	k	N	δ^{kn}_{Acc}	δ^{kn}_{Acc}	ϕkn
20_test.tif	6	4	0.95558	0.01995	0.76845
	6	3	0.95588	0.02011	0.76873
	5	4	0.95576	0.02036	0.76868
	5	3	0.96342	0.07615	0.78597

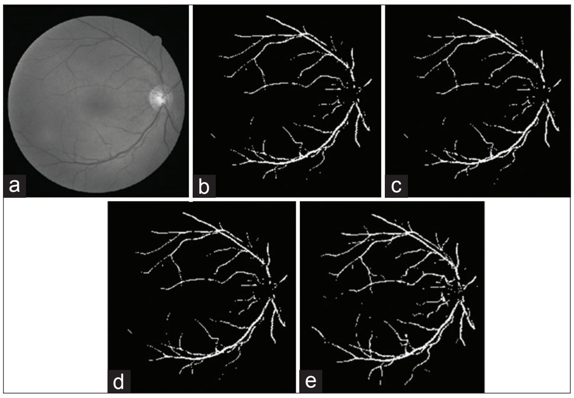

Figure 4: Segmentation of image 20_test.tif: (a) Initial image, (b) segmentation at clustering on 6 and 4 classes, (c) segmentation at clustering on 6 and 3 classes, (d) segmentation at clustering on 5 and 4 classes, (e) segmentation at clustering on 5 and 3 classes

The data that are given in the table show that variant of clustering on 5 and 3 classes is preferable, respectively, for the segmentation of thick and thin vessels.

For this clustering, the result of segmentation has rather high accuracy δ^{kn}_{Acc} (1), small first kind error E^{kn}_{FP} (2), and relatively large value of the linear convolution of the criteria ϕ^{kn} (3).

For the purpose of visual analysis of the results of the retinal blood vessel segmentation based on the k-means clustering, the images of segmentation results that correspond to different values of k and n for the clustering of thick and thin vessels, respectively, are given on test image from DRIVE base in Figure 4.

CONCLUSION

The results as shown in Figure 4 show the advantage of using clustering for k and n, taking the values of 5 and 3 classes, respectively. There is not enough complete segmentation of the vessels with other values of these parameters. Thus, the results of computational experiments demonstrated the operability and effectiveness of the analyzed method of the retinal blood vessels segmentation. It was found that it is rational to apply clustering on 5 and 3 classes, respectively, in the segmentation of thick and thin blood vessels. With this partitioning, segmentation clearly shows the vascular system of the eye fundus on the resulting binary image.

SUMMARY

It was revealed that digital medicine image processing is an actual topic at present and it is widely used in various fields of medicine, including diagnosis of the eye fundus. An analysis of the dependence of the blood vessel segmentation results on the image of the eye fundus from various partitions to pixel classes corresponding to thick and thin vessels obtained by k-means clustering was made. The analysis of the influence of the selected number of classes on the results of the segmentation of thick and thin vessels was carried out.

The computational experiments were carried out in the environment of engineering calculations Matlab on image from the public DRIVE database. The results of the computational experiments demonstrated the operability and effectiveness of the analyzed method of the retinal blood vessel segmentation based on contrast-limited adaptive histogram equalization, morphological filtering, k-means clustering, and matched filtering.

REFERENCES

1. Oatman LE. Diagnostics of the Fundus Oculi. Moscow: Kniga po Trebovaniu; 2018. p. 48.
2. Cansky GG, Milevsky SA, Damato BA, Tanner V. Diseases of the Ocular Fundus. Oxford: MED Press-Inform; 2009. p. 424.
3. Nasonov AV, Chernomorets AA, Krilov AS, Rodin AS. Application of Morphological Amoebas Method for the Allocation of Vessels on Images of an Eye-Ground. Vol. 2. Works of the 13th International Conference "Digital Processing of Signals and Its Application" (DSPA' 2011); 2011. p. 158-61.
4. Batishchev DS, Mikhelev VM. High-performance computer system infrastructure for cloud service implementation for storing and analyzing personal medical data. Nauchnye Vedomosti BelGU. Vol. 223. Seriya: Ekonomika. Informatika; 2016. p. 88-92.
5. Nugroho AA. A Generic Framework for Medical Image Segmentation. Saarbrücken: LAP Lambert Academic Publishing; 2012. p. 56.
6. Astakhov U, Dal N. Ophtalmoskopia, N-L; 2011. p. 48.
7. Chernomorets DA, Mikhelev VM. Predobrabotka ixobrazheniy glaznogo dha. Informatika: Problem, metodologia, tehnologuu: Sbornik materialov XVII mezhdunarodnoy nauchno-metodicheskoy konferentsii: v 5 t., pod redaktsiey N.A. Tukacheva, A.A. Krilovetskogo; Voronezh, Izdatelstvo "Nauchno-issledovatelskie publikatsii" (OOO "Valborn") 2017;3:193-8.
8. 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;8:263-9.
9. Can A, Shen H, Turner JN, Tanenbaum HL, Roysam B. Rapid automated tracing and feature extraction from retinal fundus images using direct exploratory algorithms. IEEE Trans Inf Technol Biomed 1999;3:125-38.
10. Hoover A, Kouznetsova V, Goldbaum M. Locating blood vessels in retinal images by piece-wise threshold probing of a matched filter response. IEEE Trans Med Imaging 2000;19:203-10.
11. Soares J, Leandro J, Cesar R Jr, Jelinek H, Cree M. Retinal vessel segmentation using the 2-D Gabor wavelet and supervised classification. IEEE Trans Med Imaging 2006;25:1214-22.
12. Zana F, Klein JC. Segmentation of vessel-like patterns using mathematical morphology and curvature evaluation. IEEE Trans Image Process 2002;10:1010-9.
13. Sun K, Chen Z, Jiang S, Wang Y. Morphological multiscale enhancement, fuzzy filter and watershed for vascular tree extraction in angiogram. J Med Syst 2011;35:811-24.
14. Iliasova NU. Methods of digital analysis of human vascular system. A review of the literature. Comput Optics 2013;37. Available from: http://www.computeroptics.smr.ru. [Last accessed on 2017 May 20].

15. Li Q, Jane Y, Zhang D. Vessel segmentation and width estimation in retinal images using multiscale production of matched filter responses. Expert Syst Appl 2012;39:7600-10.
16. Nguyen UT, Bhuiyan A, Park LA, Ramamohanarao K. An effective retinal blood vessel segmentation method using multi - scale line detection. Pattern Recognit 2013;46:703-15.
17. Patasius M, Marozas V, Jegelevieius D, Lukosevieius A. Recursive algorithm for blood vessel detection in eye fundus images: Preliminary results. IFMBE Proc 2009;25/11:212-5.
18. Chernomorets DA, Mikhelev VM. On retinal thick and thin blood vessels segmentation. Nauchnye vedomosti BelGU. Vol. 265. Seriya: Ekonomika. Informatika; 2017. p. 113-21.
19. Kuleshov A, Sushkova L, Shevchenko N. Metodi i Algoritmi Obrabotki Izobrazheniy. Saarbrukken: LAP Lambert Academic Publishing; 2012. p. 104.
20. Zhao Y, Liu Y, Wu X, Harding SP, Zheng Y. Retinal vessel segmentation: An efficient graph cut approach with retinex and local phase. PLoS One 2015;10:e0122332.
21. Research Section, Digital Retinal Image for Vessel Extraction (DRIVE) Database, Utrecht, the Netherlands, University Medical Center Utrecht, Image Sciences Institute. Available from: http://www.isi.uu.nl/Research/Databases/DRIVE. [Last accessed on 2017 Apr 21].

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