# Optimization of retinal blood vessel segmentation based on Gabor filters and particle swarm optimization

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**ABSTRACT**

The structure of the retinal blood vessels can be obtained by segmenting the fundus images. A fundus image can be gained through color fundus photography or fluorescein angiography (FA). The fundus image produced by the camera can cause noise which can reduce the quality of the fundus image. To reduce the noise, this research uses the non-local means filter (NLMF). For texture analysis, the study uses Gabor filters due to the frequencies of this filter as the same as the human visual system. The segmenting process of the retinal blood vessel is performed using K-means optimized by particle swarm optimization (PSO). The accuracy of 0.9525, the precision of 0.8330, the sensitivity of 0.5817, and the specificity of 0.9880 are obtained using the proposed method.



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## 1. INTRODUCTION

A fundus image is one of the components used to diagnose a disease such as diabetic retinopathy (DR), glaucoma, hypertension, and other diseases related to the eyes [1], [2]. Early diagnosis of the fundus can effectively prevent or treat patients with eye-related health problems[3]. Inside the fundus, there are blood vessels that can diagnose diseases. Changes in the retinal blood vessels' characteristics are an important indicator of whether a person has DR, glaucoma, hypertension, or others [4].

The structure of the retinal blood vessels can be obtained by segmenting the fundus image. Generally, this process is done manually by a doctor or a pathologist. But this method is not efficient because if the number of photos to be segmented is vast, then the segmentation process will take a long time and cause inconsistencies in the segmentation process. Therefore, various automation methods for blood vessel segmentation have been proposed by many researchers.

The blood vessel segmentation method is divided into rule-based and machine learning-based categories. The rule-based category is performed by tracking edges on the vessel. In contrast, in the machine learning category, the vessel segmentation process is performed using a supervised, or unsupervised learning approach [1], [5]. Although blood vessel segmentation is divided into two categories, many studies have combined rule-based with machine learning based.

To get retinal blood vessel segmentation, Wicaksono *et al.* [6] uses fuzzy C-means combined with Gabor filters to segment the retinal blood vessel image. In contrast to [6] which uses fuzzy C-means, Ali *et al.* [7] compares the use of Otsu Thresholding, isodata, and K-means combined with Gabor filters to segment the blood vessel image. The use of Gabor filters aims to detect the textures of the image [8]. The result shows that the segmentation using Gabor filters has a better result than without using Gabor filters [6], [7]. However, the segmentation using thresholding requires a long computation time [9], as well as K-means which is constrained by the determination of the initial centroid which causes the local optimum [10], [11].

Unlike the research of Erwin *et al.* [9] and Hemeida *et al.* [12] which optimizes retinal blood vessel segmentation using a thresholding approach, this research aims to segment the blood vessel segmentation using a clustering approach optimized by particle swarm optimization (PSO). PSO is widely used in various kinds of research [13], in clustering, classification [14], [15], or other segmentation techniques [2], [16]. PSO is included in swarm intelligence [17] and can optimize computing processes [18]. This research uses K-means to segment the image. PSO is used to find the centroid in the clustering process. The clustering approach is chosen because it does not require a lot of training data compared to using a supervised learning approach [19].

## 2. METHOD

In general, fundus images used to detect DR, Glaucoma, and hypertension are divided into two types: fluorescein angiography (FA) and color fundus photography [20]-[22]. Blood vessel segmentation in this study uses the fundus image of the digital retinal images for vessel extraction (DRIVE) dataset. This dataset consists of two main folders: the training folder and the testing folder. The data used for segmentation is data that comes from the training folder. In the training folder, there are manual segmentation images used as ground truth.

The proposed method in this study is shown in Figure 1. In the early stages of segmentation, the colored fundus image is extracted into 3 separate channels, namely red (R), green (G), and blue (B) channels. Compared to the red and blue channels, the green channel has higher contrast than the other two channels [23], so the next stage of the blood vessel segmentation process uses the green channel image as a reference image. To increase the intensity of the contour of the blood vessel, the green channel fundus image is contrasted using contrast limited adaptive histogram equalization (CLAHE). CLAHE is widely used in medical images [24]. CLAHE is a variant of adaptive histogram equalization (AHE) which works based on a grid. The grid used in this study is 10x10 in size.

The segmentation using CLAHE in the processing stage can improve segmentation performance [25], [26]. However, increasing the contrast in the image causes an increase in noise. A noise that appears in the image can cause uncertainty and ambiguity when the clustering process is performed [27]. Feng *et al.* [28] and Joshi *et al.* [29] use the non-local means filter (NLMF) to reduce the noise that appears in medical images. In this research, the researchers used NLMF with the filtering/cut-off distance h = 10 and standard deviation = 0.01. Generally, NLMF at point p, NLu(p), is defined as (1):

$$NLu(p) = \frac{1}{C(p)} \int f(d(B(p), B(q)))u(q)dq, \tag{1}$$

where (B(P), B(q)) is the Euclidean distance between points p and q, and C(p) is the normalization factor. The calculation of the weight factor of the NLMF is performed using an exponential,

$$w(p,q) = \exp\left(-\frac{max(d^2 - 2\sigma^2, 0)}{h^2}\right) \tag{2}$$

where $\sigma$ represents the standard deviation of the noise, and h represents the filtering parameter that depends on the value of $\sigma$. Measurement of denoised image quality is conducted using peak signal noise ratio (PSNR).

The next step is a morphological operation process. This process aims to increase the blood vessel's contour, remove the macula, and remove the optical disk in the fundus image. After that, the contour of the image will be processed using Gabor filters. The Gabor filters are widely used in research for texture analysis and are modulated by the Gauss function [30]. The Gabor filters have a frequency similar to that of the human visual system [4]. Gabor filters are one of the popular methods for texture analysis and are used in many applications, such as texture segmentation, edge detection, retina identification [31], or others related to computer vision or image processing. Gabor filters are also successful to enhance the texture of the images related to the medical images [32]-[34]. The impulse response of the Gabor filters in 2-D spatial space is:

$$h(x,y) = g(x,y)\cos\left(2\pi\left(u_0 x\right)\right), \tag{3}$$

where $g(x,y)$ is defined as:

$$g(x, y) = \exp\left\{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right\}, \tag{4}$$

where $u_0$ is the frequency of sinusoidal plane wave along the x-axis, $\sigma_x$ and $\sigma_y$ are the space constants along the x and y axes [8].

The segmentation process is performed by using K-means on the image that has been processed by using Gabor filters. In this research, the number of clusters is 2 (0 for indicating black color, and 255 for indicating white color). To optimize the clustering process, we use PSO to find the centroid of the cluster. PSO uses random particles (the position **x** and the velocity **v** ) to search the global optimum based on a fitness function. The best position of the particles is denoted by gbest:

$$\text{gbest} \in \{p_1(t), p_2(t), ..., p_m(t)\}, \tag{5}$$

where $p_i$ denotes the best position of particle i. The position and velocity of particle i are updated using:

$$v_i(t) = wv_i(t) + c_1 r_1 (p_i(t) - x_i(t)) + c_2 r_2 (gbest - x_i(t)), \tag{6}$$

$$x_i(t+1) = x_i(t) + v_i(t+1), \tag{7}$$

where $w$ is weighting factor, c1 and c2 are the acceleration constants, r1 and r2 are random numbers [35].

Measurement of blood vessel segmentation performance is performed by searching for evaluation metrics consisting of accuracy, precision, sensitivity, and specificities. The components of the evaluation metrics depend on true positive (TP), true negative (TN), false positive (FP), and false negative (FN). The sensitivity shows the algorithm's ability to detect vessel pixels, while the specificity shows the algorithm's ability to detect non-vessel pixels [1].

$$\text{Accuracy} = \frac{TP + TN}{TP + FN + FP + TN}, \tag{8}$$

$$\text{Precision} = \frac{TP}{TP + FP}, \tag{9}$$

$$\text{Sensitivity} = \frac{TP}{TP + FN}, \tag{10}$$

$$\text{Specificity} = \frac{TN}{TN + FP}, \tag{11}$$

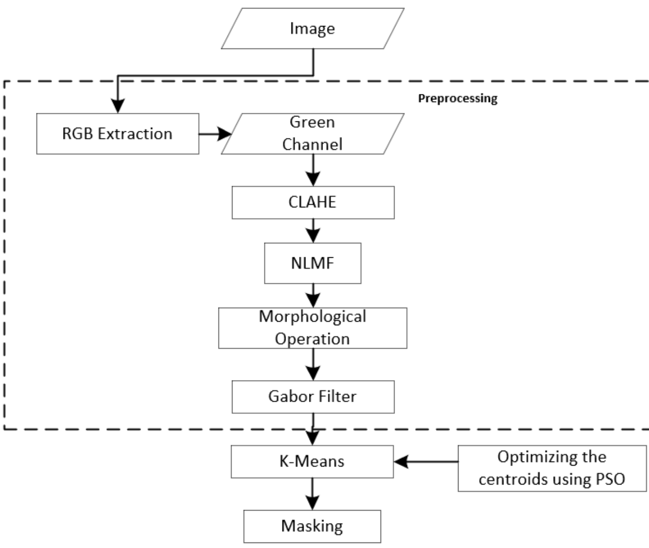


Figure 1. The research workflow

## 3. RESULTS AND DISCUSSION

The results of the fundus image preprocessing can be seen in Figure 2. Figure 2(a) shows the color fundus image in the training folder. Figure 2(b) shows the green channel of the image that is extracted from the RGB image. Figure 2(c) shows the image contrast increased by using CLAHE, and Figure 2(d) shows the image that is denoised by using NLFM. Liu and Liu [39] shows that the denoise using NLMF can not only reduce noise but also preserve the image structure. Based on the comparison of the peak signal ratio (PSNR) value for 24_training.tif image sample, the PNSR of the denoise image has increased by 0.46, which indicates that the noise in the CLAHE image has decreased (Table 1). The results of the morphological operation can be seen in Figure 2(d). Morphological operation aims to eliminate the optical disk and macula in the fundus image. The optical disk has higher contrast than the contours of the other fundus components, so if it is not removed, the optical disk will be segmented and can be considered as a blood vessel.

Table 1. Comparison PNSR value: CLAHE and denoised image toward green channel

| PNSR | CLAHE | Denoised image |
|---|---|---|
| Green channel | 19.71 | 20.17 |

The morphology used in this process is dilation with a kernel size of 10x10. The results of the dilation process can be seen in Figure 2(e). To enhance the texture of the image resulting from the dilation process, the research uses Gabor filters. The result of the texture analysis for the fundus image using Gabor filters is shown in Figure 2(f). Adak's research [40] also shows that the use of Gabor filters in detecting edges on magnetic resonance imaging (MRI) images gives better results than using Sobel, Prewitt, Roberts, Canny, and Laplacian of Gaussian. Figure 3(a) shows the ground truth image of retinal blood vessel segmentation. The experimental result shows that segmentation using K-means optimized by PSO and Gabor filters Figure 3(b) is better than segmentation without Gabor filters (Figure 3(c)). Without using Gabor filters, the segmentation result shows that there is still a segmented macula (Figure 3(c)). The same result is also obtained by Wiharto and Suryani [41], where a macula still appeared in the segmentation result using K-means and without Gabor filters. However, if we compare the ground truth image (Figure 3(a)) and the proposed method (Figure 3(b)), the proposed method has not been able to detect thin blood vessels.

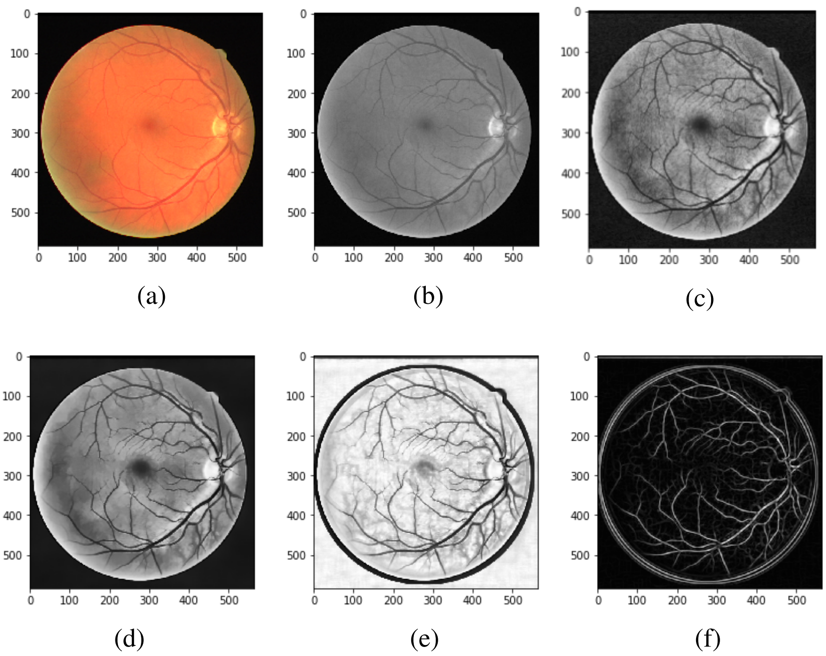


Figure 2. Feature extraction of (a) color fundus image, (b) green channel image, (c) CLAHE image, (d) denoised image, (e) image resulted by morphological operation, and (f) Gabor filter image

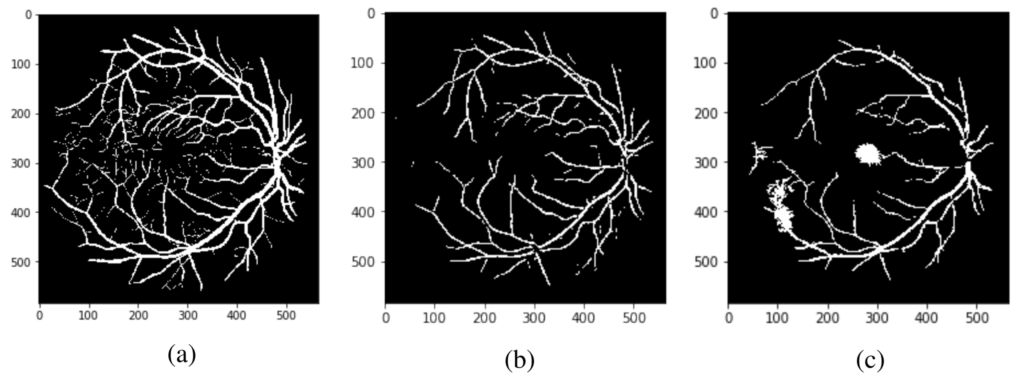


Figure 3. Comparison of segmentation results based on different methods (a) ground truth, (b) PSO K-means + Gabor filters, and (c) segmentation using the proposed method without Gabor filters

The performance of segmentation using the clustering method can be seen in Table 2. The accuracy has the highest value compared to [36]-[38], as well as precision which has a better value than [36] (the results are not available in [7], [37], [38]). Although Khatter's research [36] uses Gabor filter to improve Robinson compass mask and fuzzy C-means, in the segmentation results, there is still segmented noise. Therefore, in this research, NLMF is performed to reduce noise in the image. In Table 2, using the proposed method, accuracy is better than the [7] and [37] studies where they also use K-means for retinal blood vessel segmentation. The increase in accuracy using PSO is also produced by Gong *et al.* [42] study, which shows the use of PSO can improve clustering performance results. However, the sensitivity of the proposed method shows a smaller value than in other studies. Therefore, the optimization of retinal blood vessels especially thin blood vessels needs to be improved.

Table 2. Performance of different segmentation (clustering) method on DRIVE database

| | Accuracy | Precision | Sensitivity | Specificity |
|---|---|---|---|---|
| Khatter *et al*. [36] | 0.9371 | 0.6326 | N/A | N/A |
| Ali *et al*. [7] | 0.9425 | N/A | 0.7206 | 0.9757 |
| Saffarzadeh *et al*. [37] | 0.9387 | N/A | N/A | N/A |
| Akhavan and Faer *et al*. [38] | 0.9513 | N/A | 0.7252 | 0.9733 |
| Proposed method | 0.9525 | 0.8330 | 0.5817 | 0.9880 |

## 4. CONCLUSION

The use of Gabor filters in the segmentation process using K-means which is optimized using PSO shows better results than without using Gabor filter. In the processing stage, NLMF are used to reduce the noise generated by the CLAHE process. The accuracy of 0.9525, the precision of 0.8330, the sensitivity of 0.5817, and the specificity of 0.9880 are obtained using the proposed method to perform the blood vessel segmentation tested on the DRIVE database.

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