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Research Article

Retinal Vessel Extraction based on Firefly Algorithm guided Multi-scale Matched Filter

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Abstract

Retinal image inspection is necessary to perceive and supervise a variety of retinal diseases. Extraction of vital retinal region is generally chosen to have a clear idea about the disease and the infected section. In the literature, the idea of matched filter is broadly accepted by the researchers to extract the retina vessel from the RGB retinal fundus images. In the proposed work, Firefly Algorithm (FA) assisted multi-scale matched filter is designed to extract the retinal vessel from a chosen RGB retinal image database. The major aim of the proposed work is to determine the optimal filter parameters of the multi-scale matched filter in order to achieve better accuracy in retinal vessel segmentation. During this study, the proposed work is tested on the DRIVE retinal image database. The efficiency of the proposed approach is confirmed by computing the image similarity measures, such as Jaccard, Dice, False Positive Rate (FPR) and False Negative Rate (FNR). The image statistical measures, such as sensitivity, specificity and accuracy are also calculated. These values are then compared against other similar procedures available in the literature and found that, the sensitivity and specificity of the proposed approach is better compared to the alternatives considered in this work.

Keywords: Fundus retinal image; firefly algorithm; multi-scale matched filter; performance evaluation.

Introduction

Retina is the innermost layer of the eye. Automatic examinations of vital retinal parts are extremely significant to discover, analyse and to provide well-organized treatment for the retina related and other diseases. Retinal frames obtained with ocular fundus image [1-4], fluorescein angiography [5], and optical coherence tomography [6] are widely considered to analyse various parts of the retina. Usually, retinal images are commonly employed in the diagnosis and treatment of diabetic retinopathy [4], optic nerve disorder [7], glaucoma [8], retinal vasculature [1-3], severity of malaria [9] and cardiovascular diseases [10].

Wound, geometrical and physical variation in blood vessels are widely analysed to detect the assortment of diseases and these variation may include the change in shape, size, and appearance of the retinal parts. Various retinal diseases and its effects are clearly discussed in the literature [11,12]. Among them, blood vessel segmentation is an important task in retinal disease examination.

Earlier works confirms that, a variety of traditional and soft computing approaches are already implemented for the segmentation and localization of retinal blood vessel of the fundus image datasets [12-15]. These works also evident that, the accuracy in retinal disease identification and diagnosis mainly depends on the exactness of employed image segmentation procedure.

Retinal images are normally recorded with the most commonly used imaging procedures, such as colour fundus imaging and fluorescein angiography. The common fundus image is the combination of three channels, namely the Red (R), Green (G) and Blue (B). The RGB retinal image processing is a tedious job due to its multi-model histogram rage [15]. Hence, in the most of the works, green channel data alone is considered by the researchers to extract the retina vessel. Due to the clinical significance of retina, attaining the greatest precision is widely

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preferred during retinal image processing task. Recent work by Sreejini and Govindan [15] confirms that, heuristic algorithm based multi-scale matched filter is efficient in extracting retinal vessel from the RGB retinal image dataset. In the proposed work, Firefly Algorithm (FA) based multi-scale matched filter design is considered for the extraction and analysis of vessel from RGB fundus images.

During this study, the retinal images of DRIVE [16] database is considered. This database has 20 test images and 20 train images with the ground truth (GT) provided by the experts. The proposed experimental work is implemented on the DRIVE dataset and the extracted vessel is validated against the GT. The results of this work confirm that, proposed method is efficient in extracting the vessel from the retinal images and provides better sensitivity and specificity compared to other methods existing in the literature.

Materials and methods

This section presents the methodology adopted in the proposed work to extract the retinal vessel from the DRIVE database.

Multi-scale matched filter

The concept of Matched Filter (MF) based template matching procedure is commonly considered to solve the retinal blood vessel segmentation problem [15,17].

It works based on the following assumption:
Let, the Gaussian MF is defined as;

$$K(a,b) = -exp(-a^2 / 2\sigma^2) \ \forall |b| \leq L/2 \qquad (1)$$

where σ is the filter scale, and L is the one directional of the vessel segmentation.
During this process, *K (a,b)* is swivelled in various directions arbitrarily to identify the vessel traces. The number of kernel, *K (a,b)* depends mainly on the angle of rotation.
The related neighbourhood values can be expressed as;

$$NH = \{(u,v), |u| \leq G, |v| \leq L/2\} \qquad (2)$$

where G is the location where the Gaussian arc should be cut and this value is chosen as 3*σ.
When, the initial kernel *K(a,b)* is rotated, then a new neighbourhood, p_i is attained.

$$p_i = [u \quad v] = [a \quad b] \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \qquad (3)$$

where θ is the angle of rotation and [*u v*] the new coordinates.

The updated weights of the new kernel are then expressed as;

$$K_i(a,b) = -exp(-a^2 / 2\sigma^2) \ \forall p_i \in NH \qquad (4)$$

From Eqn. (1) and (2), it can be noted that, the accuracy of the MF depends mainly on the parameters, such as L, σ and G. In this paper, FA based three dimensional search is proposed to optimize these parameters, and this procedure is repeated twice to have the second stage values.

Firefly Algorithm

Firefly Algorithm (FA) was originally developed by Yang [18]. It is one of the most successful bio-inspired soft computing methodology, constructed by mimicking the flashing lighting patterns created by fireflies. Comprehensive explanation about FA can be found in [19-21].

Let us consider two fireflies x and y. At the time of the optimization exploration, the progress of a fascinated firefly x towards the glittering firefly y can be mathematically computed by the following location update equation:

$$X_x^{t+1} = X_x^t + \beta_0 e^{-\gamma d_{xy}^2} (X_y^t - X_x^t) + \alpha_1 . sign(rand - 1/2) \oplus B(s) \qquad (5)$$

where X_x^{t+1} is the reorganized location of x^{th} firefly, X_x^t is the early location of x^{th} firefly, $\beta_0 e^{-\gamma d_{xy}^2} (X_y^t - X_x^t)$ the attractive strength among fireflies, $B(s) = A.|s|^{\alpha/2}$ is the Brownian walk strategy, A is an arbitrary variable, β is the spatial supporter and α is the temporal supporter

Blood Vessel Segmentation

The retinal blood vessel segmentation problem is implemented to support the efficient blood vessel segmentation for RGB fundus images, as follows:
Step 1: Initialise the FA algorithm with the chosen algorithm parameters (FA constraints are assigned as follows; number of fire flies = 20, dimension of search = 3 (ie. L, σ and G), maximum iteration = 500, other parameters are assigned as in [20].
Step 2: Extract the green channel image and implement the FA based matched filter.
Step 3: Store the extracted blood vessel.
Step 4: Apply the image performance metric procedures to record the necessary data in order to validate the segmented image with the GT.

Performance metrics for extracted vessel

The accuracy of medical image segmentation is widely confirmed using a relative analysis with the expert's Ground Truth (GT). During this procedure, the image performance metrics, such as Jaccard Similarity Coefficient (JSC), Dice Similarity Coefficient (DSC), False Positive Rate (FPR), and False Negative Rate (FNR) are computed [22].
These metrics are mathematically expressed as follows [22];

$$JSC(I_{gt}, I_{pm}) = I_{gt} \cap I_{pm} / I_{gt} \cup I_{pm} \quad (6)$$

$$DSC(I_{gt}, I_{pm}) = 2(I_{gt} \cap I_{pm}) / |I_{gt}| \cup |I_{pm}| \quad (7)$$

$$FPR(I_{gt}, I_{pm}) = (I_{gt} / I_{pm}) / (I_{gt} \cup I_{pm}) \quad (8)$$

$$FNR(I_{gt}, I_{pm}) = (I_{pm} / I_{gt}) / (I_{gt} \cup I_{pm}) \quad (9)$$

where, I_{gt} represents the Ground Truth (GT) and I_{pm} stands for the segmented image with proposed method.

Well known related performance metrics, such as sensitivity, specificity, and accuracy also considered to analyse the segmented blood vessel data [15,23].
These measures are denoted as;
Sensitivity = TP / (TP+FN) (10)
Specificity = TN/ (TN+FP) (11)
Accuracy = (TP+TN)/(TP+TN+FP+FN) (12)

- when GT and segmented image are high, then it is a True Positive (TP)
- when GT is high and segmented image is low, then it is a False Positive (FP)
- when GT is low and segmented image is high, then it is a False Negative (FN)
- when GT and segmented image are low, then it is a False Negative (TN) where low and high represents the size (pixel value) of images.

Results and discussion

This section presents the experimental results and its discussions. The primary motivation behind this research is to develop a heuristic algorithm assisted automated vessel segmentation procedure for the RGB retina images. The blood vessel extraction procedure is initially implemented on the test images (20 numbers). The filter parameter optimization is carried using the FA with a three dimension search and the following values are arrived for L, σ and G: (2, 2, 8) and (2, 3, 6). In order to verify the result, first five test images are initially considered and its Ground Truth (GT) values and the extracted blood vessels are depicted in Table 1. Similar results are obtained for other test and train images existing in the DRIVE database. The outcome of the proposed approach is then validated using a comparative study between the extracted vessel and the GT existing in the database. Figure 1 presents the pixel wise comparison of the chosen GT image and extracted vessel image. The common image similarity measures and the statistical methods are computed using equations (6) to (12) and the values are clearly presented in Table 2 and Table 3. The average values of these tables confirm that, the proposed approach offers satisfactory result on the DRIVE database chosen for the study.

Finally, a detailed assessment is performed by considering the average values of the sensitivity, specificity and accuracy of the proposed approach with the results of other procedures existing in the literature as shown in Table 4. Figure 2 also presents the graphical version of image statistical index obtained for the DRIVE dataset. From these results, it can be noted that, the proposed approach offers improved sensitivity than the alternatives considered in this study. The specificity is also better and very close to the PSO based multi-scale matched filter, recently discussed by Sreejini and Govindan [15]. The segmentation accuracy of the FA based multi-scale matched filter is poor than the other methods shown in Table 4 and which can be improved using recent versions of FA algorithms existing in the literature [30].

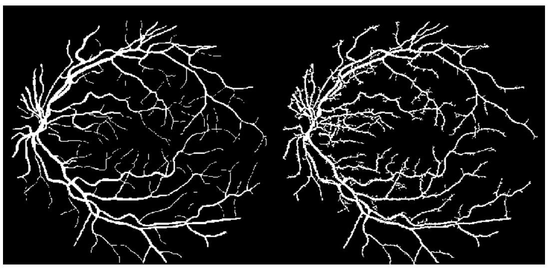


Figure 1. Comparison of ground truth and extracted vessel

Table 1. Chosen test images of DRIVE database and the extracted blood vessel

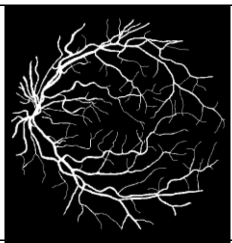
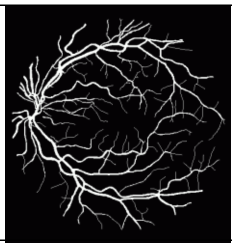
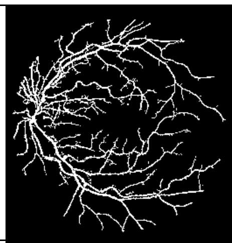
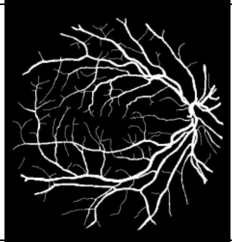
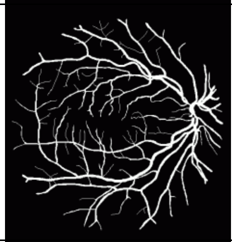
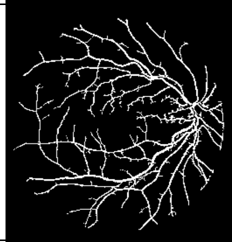
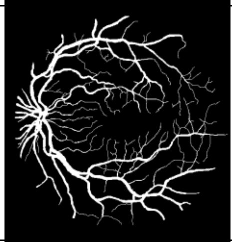
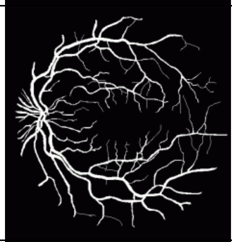
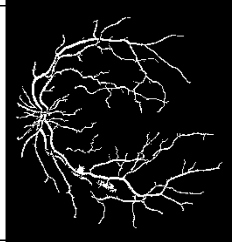
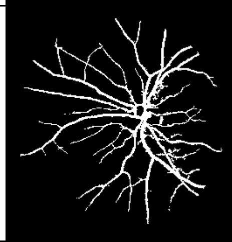
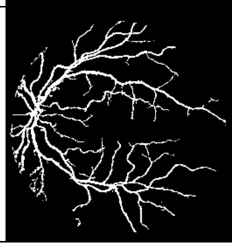
Pseudo name	Test image	Ground truth1	Ground truth2	Extracted vessel
01_test				
02_test				
03_test				
04_test				
05_test				

Table 2. Image similarity metrics between ground truth1 and extracted vessel

Pseudo name	Jaccard	Dice	FPR	FNR	Sensitivity	Specificity	Accuracy
01_test	0.6011	0.7508	0.3272	0.2023	0.7977	0.9679	0.8787
02_test	0.5968	0.7475	0.1754	0.2985	0.8014	0.9799	0.8291
03_test	0.5198	0.6840	0.1110	0.4225	0.7775	0.9877	0.8552
04_test	0.6367	0.7780	0.1553	0.2644	0.7355	0.9842	0.8508
05_test	0.6055	0.7543	0.1960	0.2758	0.7241	0.9797	0.8423
Average	0.5920	0.7429	0.1930	0.2927	0.7672	0.9799	0.8512

Table 3. Image similarity metrics between ground truth2 and extracted vessel

Pseudo name	Jaccard	Dice	FPR	FNR	Sensitivity	Specificity	Accuracy
01_test	0.6049	0.7538	0.3384	0.1904	0.8095	0.9675	0.8850
02_test	0.6383	0.7792	0.1544	0.2631	0.7368	0.9827	0.8509
03_test	0.5689	0.7252	0.1291	0.3577	0.7422	0.9873	0.8935
04_test	0.6524	0.7897	0.1713	0.2358	0.7641	0.9835	0.8669
05_test	0.6643	0.7983	0.2381	0.1775	0.8224	0.9789	0.8973
Average	0.6258	0.7692	0.2063	0.2449	0.7750	0.9800	0.8787

Table 4. Performance evaluation between proposed approach and existing methods

Methods	Sensitivity	Specificity	Accuracy
Frederic and Klein [24]	0.6971	0.9377	0.8984
Moazam et al. [25]	0.7152	0.9769	0.9430
Bob et al. [26]	0.7120	0.9724	0.9382
Perez et al. [27]	0.6600	0.9612	0.9220
Martinez-Perez et al. [28]	0.7246	0.9655	0.9344
Saleh and Ali [29]	0.7352	0.9795	0.9458
Sreejini and Govindan [15]	0.7132	***0.9866***	***0.9633***
Proposed approach	***0.7916***	0.9803	0.8719

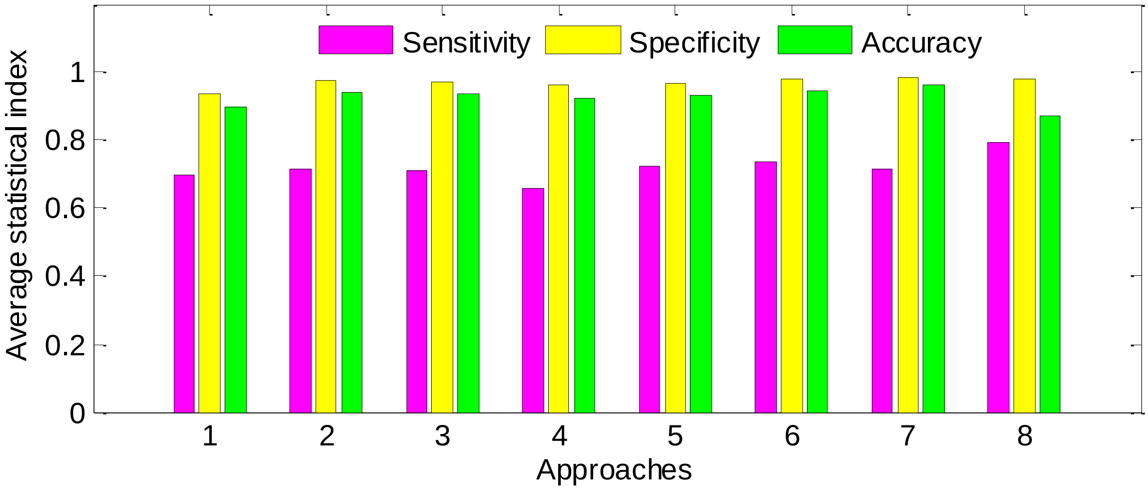


Figure 2. Performance assessment based on image statistical index

Conclusions

In the present paper, Firefly Algorithm (FA) based automated procedure is implemented to segment the blood vessel from retinal image dataset. A novel FA based multi-scale matched filter is designed to analyse the DRIVE database. The extracted blood vessel of the test and train images are then compared with the expert's ground truths and the image similarity measures and statistical measures are computed. The result of this work confirms that, proposed approach offers better values of the Jaccard, dice co-efficient, FPR and FNR. A comparative study between the proposed approach and the other approaches in the literature also confirms that, proposed approach is efficient in offering better values of the sensitivity and specificity. Hence, the FA based procedure is clinically significant and in future, it can be considered to analyse the real time retina images.

Conflict of interest

Authors declare there are no conflicts of interest.

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