A Comprehensive Study of Retinal Vessel Classification Methods in Fundus Images for Detection of Hypertensive Retinopathy and Cardiovascular Diseases

J. Anitha Gnanaselvi and G. Maria Kalavathy

Abstract Quantitative studies for classification of retinal vessels using new computer-assisted retinal fundus imaging system have allowed the researchers to understand the influence of systemic on retinal vascular caliber. These retinal vascular caliber changes reflect the cumulative response to cardiovascular risk factor. Hypertensive retinopathy can be detected in earlier stage by analyzing the retinal image. Nowadays, it is obvious that there is a relationship between changes in the retinal vessel structure and the most common diseases such as hypertension, stroke, cardiovascular diseases, those can be detected by noninvasive retinal fundus image. The proposed approach of applying an image processing technique, the aforementioned disease can be diagnosed earlier by retinal fundus image. To achieve the precise measurement of the retinal image parameters, the classification of blood vessels such as arteries and veins is necessary. These classifications of arteries and veins can be achieved through the retinal fundus image. The retinal vessel classification is based on visual and geometric features from these classified images into arteries and veins for the detection of hypertensive retinopathy, stroke, and cardiovascular risk factor. This classification of retinal fundus image is essential for early diagnosis of aforementioned diseases. The retinal arteriolar caliber which is narrower and smaller, that is associated with older age, will predict the incidence of diabetic retinopathy and cardiovascular risk factor. Similarly, retinal venular caliber which is wider, that is associated with younger age, will predict the incidence of risks of stroke and coronary heart diseases. This could suggest the possibility of using this model of fundus image in classification approaches. Finally, the selected attributes of classification are applied through the genetic algorithm with radial basis function neural network for diagnosis of the disease in order to improve the classification accuracy with less computational cost time.

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1 Introduction

Diabetic retinopathy (DR) means common problem of diabetes which damages the retinal vascular area. Mostly, it affects the blood vessels in retina. One of the major issues in diabetic retinopathy is visual impairment. This is because of the new blood vessel growth in retina in proliferative retinopathy. There are several categories to predict the early diagnosis of diseases. One of the best methods is to predict the DR by using the fundus image, this fundus image is considered to be the initial and basic screening process in diabetic retinopathy prediction.

Among the several blood vessels, the retinal blood vessel network is visible and is suitable for noninvasive imaging method in our body. So, the retinal blood vessel is considered to be the reliable tool for early diagnosis of DR. In order to perform the analysis, the classification of blood vessel is done based on geometric features of vessel network. In retinal image analysis, the accurate measurement of retinal vessel parameters is considered to be an important problem in eye research. There are several parameters measured from the retinal vessel. This includes the thickness and curvature of the vessels and also the measurement of the arteriolar–venular ratio.

The arteriolar–venular ratio is considered as the essential parameter for early prediction and diagnosis of diseases which includes the hypertension, stroke, cardiovascular disease in youngsters, and retinopathy in child. Though there are several sets of rules that have been defined for measuring the ratio of arteriolar–venular. These include the distance from the optic disk margin; in Japan, the ratio is measured and calculated as 0.25–1 of the optic disk diameter. In the U.S., it is stated as 0.5–1 for measuring the arteriolar–venular ratio calculation.

This arteriolar–venular ratio calculation measurement includes other areas also such as localization of optic disk, retinal vessel diameter, measuring accurately, retinal vessel network image analyzing, and also for the classification of blood vessels which includes arteries and veins. This classification of blood vessel is considered as the basic step for calculating the arteriolar–venular ratio. This arteriolar–venular ratio is important for calculating the classification of blood vessels in an efficient and effective way.

The quantitative calculation of retinal vascular caliber is highly influenced in the clinical significant association outcomes such as detection of stroke and coronary heart diseases. This can be achieved by the retinal fundus image.

2 Related Work

In the modern world, by the early diagnosis many diseases can be controlled that includes the life-threatening diseases. Though there are several approaches that are existing already for the early diagnosing diseases, this deals with the two categories. First category used the machine learning popular algorithm. Genetic algorithm which is used for the feature selection of the attributes is included in the second category and it uses the radial basis functional neural network for the classification purpose in the attributes. The diabetic retinopathy diagnosed by the Pima Indian Diabetes Dataset is used for the classification purpose. The results show that it will minimize the cost of computation time and is also better in classification [1, 2].

The diabetic retinopathy (DR) mainly affects the retinal vessels in the macular region which is located in the center portion of the retina in the fundus image. These studies are based on the four main methods. It contains the preprocessing of the image and then enhancement of the fundus image. Third is the segmentation process which will segment the vessels, and finally it includes the proposed foveal avascular zone segmentation approach which is used to diagnose the diseases. This shows the results of an average in performance metrics such as specificity, sensitivity and accuracy from theses diseases are diagonsed earlier [3, 4].

There are various approaches to quantify the width and tortuosity of retinal vessels to detect cardiovascular diseases. The artery-to-venous ratio will predict the narrow arterial and venous dilatation for the detection of stroke and cardiovascular heart diseases. Here, the artery-to-venous classification method is used which provides the accurate region around the optic disk [5].

The segmentation of retinal vascular blood vessels into veins and arteries is used for quantifying the ratio of artery-to-venous diameter. It is developed to predict the cardiovascular heart disease and stroke in children. The features are extracted from the databases and used for the training and testing phase algorithm for all the vessels and it will point out whether it is vein or artery. The artery-to-vein classification approach using the receiver operator characteristic shows better results and has detected the artery and vein in the fundus image [6].

In order to achieve the accurate calculation and measurement of parameter in diagnostic features, the arteries and veins are essential. The classification parts of blood vessels in the fundus image are evaluated by different databases in different criteria. These approaches focus on the geometric features and statistical model in spatial and transform domain [7, 8].

3 Methodology and Measurement

The common method of the blood vessel classification is by utilizing the fundus image. First step is segmentation of vessels, second step is selecting the region of interest for classifications of vessels. Third step is extracting the features from various parts of the vessels. Fourth step is to classify the vectors of features. At last, final is the combination of results to determine the final label of vessel. This is considered as the existing way to classify the vessels in the fundus image.

The proposal is based on the classification of vessels into two major criteria. They are represented as automatic and semiautomatic methods.

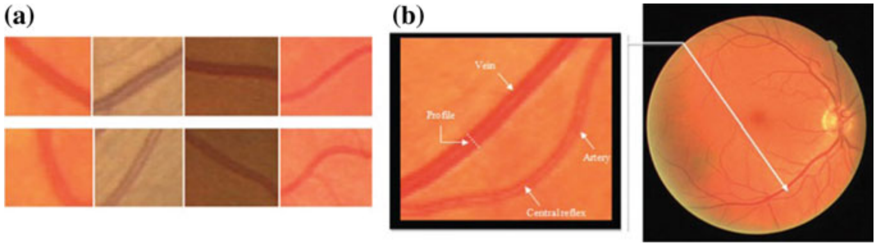

Fig. 1 **a** Sample images of vein represented in first row and artery represented in second row in fundus images, **b** Specifying central reflex and profile in a piece of a fundus image

3.1 Semiautomatic Method

The semiautomatic method for retinal vessel analyzes the artery and venous individually and it calculates geometrical and topological pixel features of each segment. This method uses the anatomical properties of veins and arteries. The semiautomatic method is a hybrid of graph-theoretic method with domain-specific knowledge and is capable of analyzing the entire vasculature (Fig. 1).

3.2 Automatic Methods

In this automatic approach, position around the optic disk is within 0.5–2 diameter of disk from its center portion and is segmented into four zones, in which each one contains one of the major arches. In these, the red channel and hue channel in each vessel segment are represented as the most discriminative features for classification. As the results, in two adjacent vessels, the darker reddish vessel is considered as vein, the vessel that has more color uniformity is considered as vein (Fig. 2).

After feature extraction, the classification criterion of vessels is based on fuzzy clustering algorithm. The Euclidean distance of each pixel from the mean value of features is calculated. After vessel classification, the data is available by vessel identifying the variation in pixels to discriminate the arteries and veins. Twenty-six fundus images have been taken in this study for assessment, in which ten fundus images were used to develop the algorithm, and 16 images were used for validation. Reported results on 15 validation images show the overall error of 12.4%. This classification procedure is performed around the optic disk and it is more preferable for optic-disk-centered images.

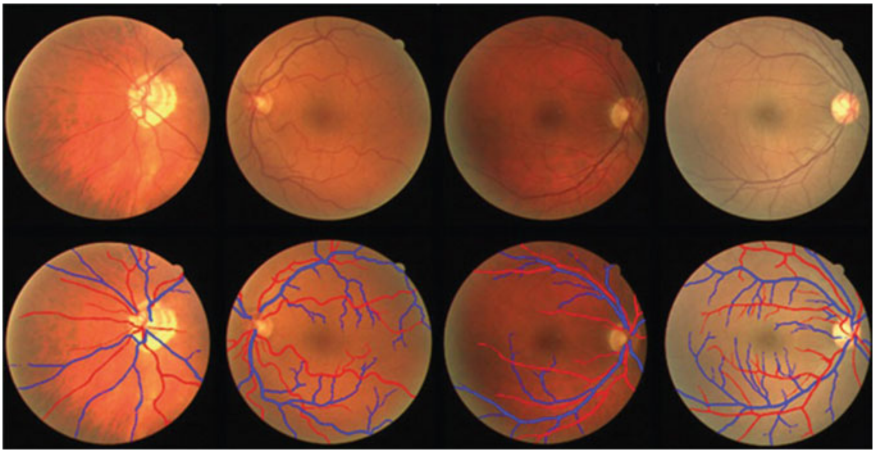

Fig. 2 First row represented some samples of fundus images from dataset and second row represented their ground truth. The arteries are represented in red lines, and the veins are represented in blue lines

3.3 Retinal Vessel Measurements

The retinal vessel calibration is based on the computer-assisted program to find out the accurate size of the fundus image. The calculation consists of actual size of the central retinal artery, the same procedure is applicable for vein, and it calculates the ratio of these abovementioned variables which is known as the artery-to-vein ratio (AVR). The result is obtained and is represented as shown in Fig. 3.

The measurement of retinal vascular caliber formula is implemented based on the theoretical and empirical methods and it can be achieved by larger quantity of retinal image with its branch point. The measurement of individual trunk vessel and branch vessel is obtained by square root mean deviation model for observing the data.

In today's population, it is difficult to find out the problem such as hypertension diabetes and ocular alignments problem such as diabetic retinopathy and glaucoma [9]. Those diseases can be measured by the retinal vessel through fundus Image. This can be measured through the refraction/axial length and retinal vascular caliber by retinal AVR (artery-to-venous) ratio calculation. However, it is very essential to identify the narrower artery and wider venous and this will result in the smaller artery-to-venous ratio. Figure 3 represents the arteriolar–venular ratio calculation measurement zones.

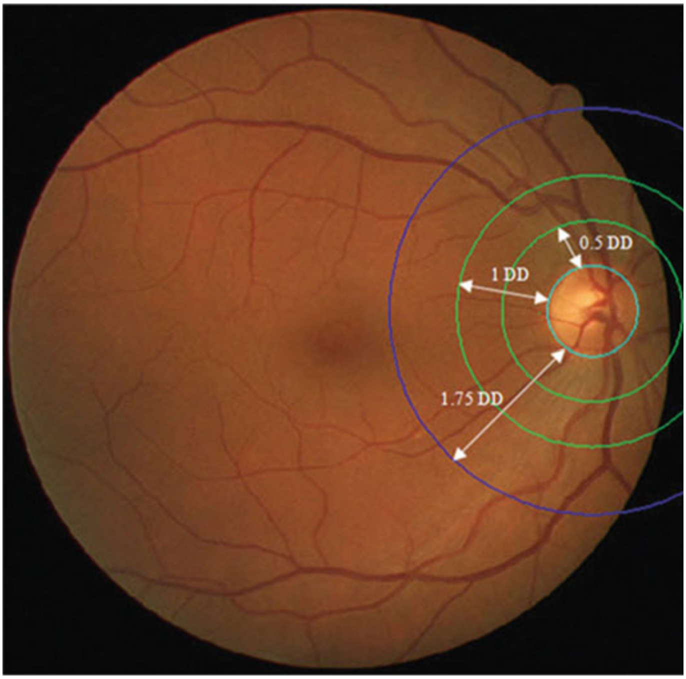

Fig. 3 Arteriolar–venular ratio (AVR) calculation measurement zones, DD = optic disk diameter

4 Results and Discussion

4.1 Proposed Methodology Using GA with RBF NN Classification of Diseases

The proposed methodology is implemented with genetic algorithm, with radial basis neural network function for classification of attributes. Here, we used Pima Indian Diabetes Dataset to perform the best diagnosis of diabetes patients in datasets. Here, the proposed method in this abovementioned algorithm is implemented to detect the diabetic patients in Pima Indian Diabetes Datasets. The genetic algorithm based on selection, crossover, and mutation operation is performed in order to obtain better attribute features and it achieves the shorter in training and testing time, that is, computational cost and time, better storage capacity, and finally increases the classification rate. Table 1 represents the proposed algorithm architecture.

The radial basis functional neural network is based on supervised learning approach. In this proposed method, the radial basis functional neural network has been used for the classification in order to diagnose the diabetes disease (Fig. 4).

The radial basis functional neural network is a supervised feedforward process which consists of one hidden layer of hidden units, which states the radial basis

Table 1 Proposed algorithm

Step1: Initialization
Step2: Store the Pima Indian Diabetes Dataset
Step3: Start the parameters of genetic algorithm
Step4: Run the genetic algorithm
Step5: (a) First generation process starts
Step6: Selection While stopping criteria not met do
(b) Crossover
(c) Mutation
(d) Selection
End
Step6: Applying the radial basis functional neural network for classification
Step7: Dataset attributes are trained
Step8: Calculation of accuracy and measuring the error
Step9: Testing the datasets
Step10: Calculation of accuracy and measuring the error
Step11: Stop the process

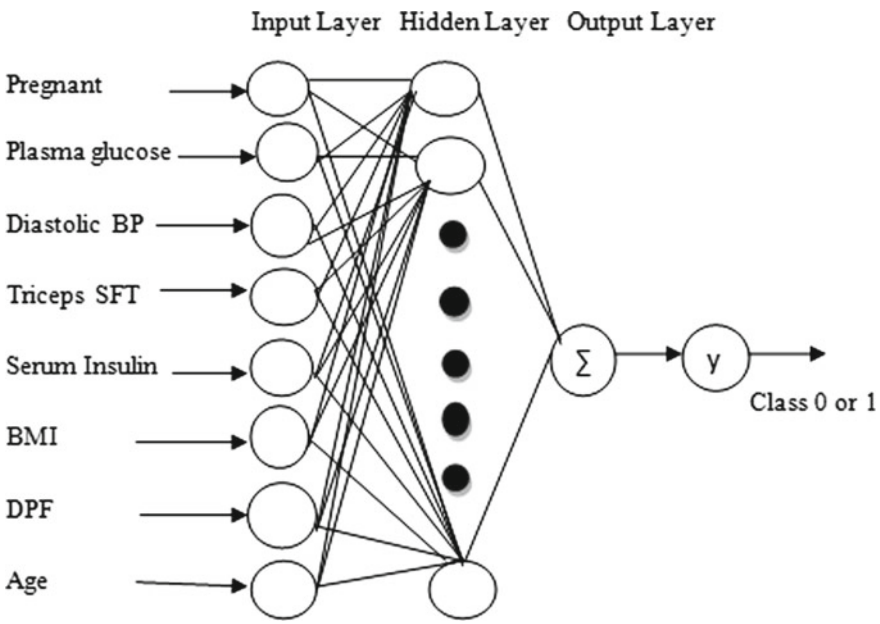

Fig. 4 Feedforward neural network model for diagnosis of diabetes

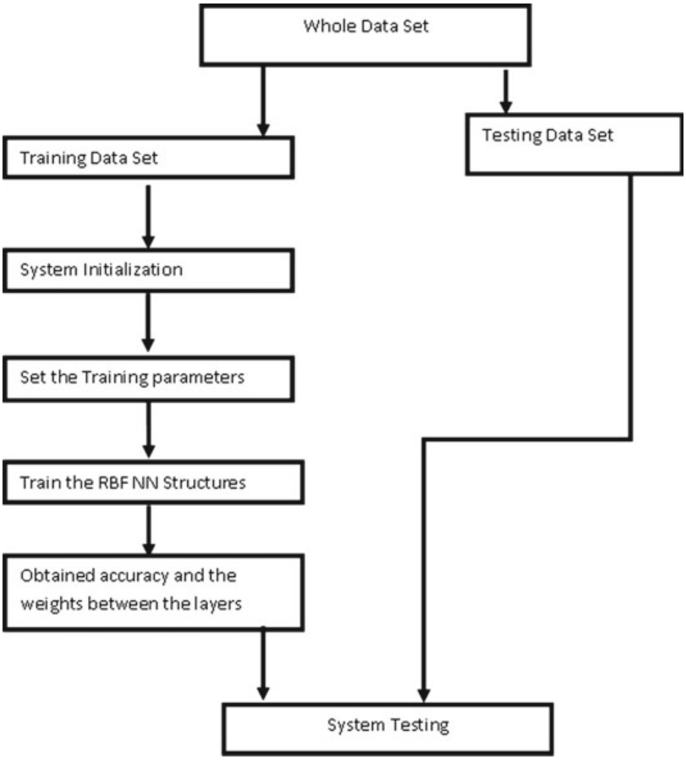

Fig. 5 The radial basis functional neural network methodology

Table 2 Genetic algorithm attributes selection

Dataset	Number of attributes	Name of the attributes	Number of instances	Number of classes
Pima Indian Diabetic Datasets with genetic algorithm	1	Plasma glucose tolerance test	768	2
	2	Serum insulin		
	3	Body mass index		
	4	Age		

functions (RBFs). These radial basis functional neural networks require a desired response to be trained in pattern classification studies. Particularly, in the present study, a training algorithm is used which normally uses a gradient descend rule for the training attributes of these networks. Figure 5 represents the radial basis functional neural network methodology (Figs. 6, 7 and Tables 2, 3).

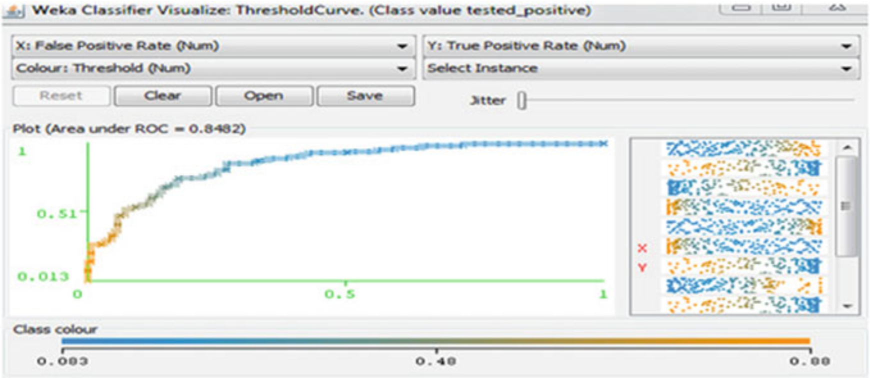

Fig. 6 ROC graph GA_RBF NN on PIDD

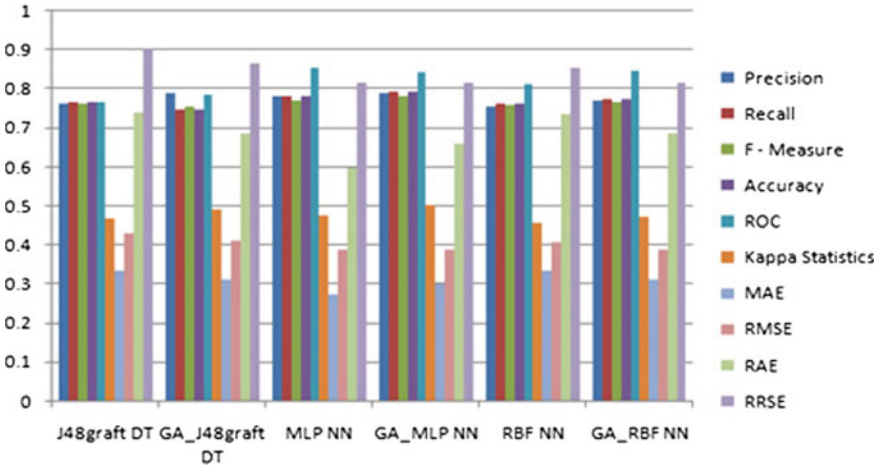

Fig. 7 Evaluation GA_RBF NN performance for PIDD

5 Conclusions and Future Directions

Diabetic blood sugar when above the desired level is considered as the world's widespread disease. The contribution of this proposed method was developed and implemented with genetic-algorithm-based radial basis functional neural network. It also determines and assesses the diabetic classification and detection of artery and vein in order to estimate the various problems including the blindness, blood pressure, kidney diseases, coronary heart diseases, nerve damages, and so on. In this proposed study, firstly, the classification has been done on Pima Indian Diabetic Datasets using radial basis functional neural network, and then using genetic algorithm for attributes selection, and thereby performing classification on the selected attribute. The results obtained are more interesting and may also happen for the exploration of the dataset.

Table 3 Results of genetic algorithm radial basis functional neural network for Pima Indian Diabetic Datasets

Measure	Training set evaluation	Testing set evaluation
Precision	0.75	0.75
Recall	0.76	0.76
F-measure	0.756	0.77
Accuracy	0.766	0.76
ROC	0.819	0.80
Mean absolute error	0.55	0.49
Root mean squared error	0.41	0.42
Relative absolute error	0.71	0.72
Root relative squared error	0.85	0.86
Kappa statistics	0.45	0.46

These classifications of arteries and veins can be achieved through the retinal fundus image. The retinal vessel classification is based on visual and geometric features from these classified images into arteries and veins for the detection of hypertension, stroke, and cardiovascular risk factor. From this, we tend to conclude that the proposed approach will help physicians to improve or take accurate decisions to do work speedily with less expense. In future, these proposed approaches can also be used for other kinds of diseases.

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