Severity Assessment of Glaucoma using Soft computing Techniques

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Abstract.
This paper elaborates the development of an automated system founded on approximate reasoning for the detection and severity assessment of glaucoma, which is considered to be dreaded visual impairment. Around 100 glaucomatous images selected after mining 180 such images formed inputs to the system. The automated systems for detection and severity assessment namely BPNN aided system, and FIS based systems were developed. The pre-processing of images proved that DBMF is the best among other filters experimented. As a testimony DBMF showed low value of MSE, high value of PSNR, and high fidelity. The three input features namely CDR, annular space width between disc and cup, and percentage constriction of annular space provided appropriate attributes for accurate damage assessment. The performance of FIS based damages assessment system shows accuracy in the range of 80% - 85%. The system based on BPNN model with topology 3-9-1 was found to be optimal. The system showed the classification accuracy in the range of 86% - 95% during testing stage and 83% - 90% during validation stage.

Keywords: Glaucoma, Automated system, CDR, DBMF, BPNN, FIS, Accuracy
DOI Number: 10.48047/NQ.2022.20.20.NQ109153 **NeuroQuantology2022;20(20): 1509-1517**

1. Introduction

It is reported that 80 million individuals worldwide will be inflicted by this dreaded visual impairment by 2020[1]. Glaucoma is metaphorically quoted as a “sneak robber of the sight” because of the reasons that the patients will never get a feeling of recognizable torment particularly during the initiation of the problem. As the disorder advances its manifestation in terms of progressive vision loss occurs. It is reported [2, 3] that in greater part of the cases, glaucoma is felt only after the loss of vision. Fundamentally vision loss occurs due to the damage caused to the optic nerve which carries the visually perceived data from the light receptor to the brain Therefore early diagnosis, detection and ophthalmic monitoring of glaucoma are very vital to avoid the patients from losing the precious vision. Ophthalmic surgeons over the globe have unequivocally asserted the fact that the end result of glaucoma is absolute blindness if it is not treated in its early stages. Due to exponential increase in the number of glaucoma inflicted patients the manual diagnosis becomes cumbersome and involves a great deal of time for an ophthalmic surgeon. In this direction automated detection and assessment of glaucoma on a regular basis will either completely avoid or at least slow down the progression of glaucoma. However, reported research is very sparse in the literature. Rest of the paper is organised as follows. Section 2 elaborates on recent related work. Section 3 explains the methodology involve in designing of the system with details about acquisition of images, pre-processing of images and selection of efficient filters. The section 4 elucidates the modalities involved in the assessment of damage using FIS and BPNN. In section 5 the paper gets concluded

2. Related works

In most of image processing as well as computer vision-based applications, four ordered steps are followed. Justifiably, it should start with data acquisition, preprocessing of the visual data, eliciting semantic details from the images or videos, and object recognition. These processes and their order is the same across almost all computer vision related applications irrespective of the domain. As far as civil engineering is concerned Automation in Construction, an international journal publishes computer vision related findings and applications to the extent of 48% of its total publications [9].
Detection and assessment of Glaucoma has received a substantial attention from researchers across the globe. This is driven by the fact that 60 million people suffered vision impairment worldwide during 2020[4]. This is caused by irreparable damage to the optic nerves. It is very much difficult to diagnose glaucoma at its formative stage when it will be slowly progressing. For the automated methods of detection researchers have widely used digital color fundus images. The detection of

glaucoma is challenging because the texture of OD and its surroundings differs from image to image making it difficult to detect boundaries of OD. Due to inter twinning of blood vessels and distortion of cup as well as the disk becomes highly difficult. Localization and segmentation of optic disk is a challenging task. Researchers have published many papers on segmentation of disk and the cup and also proposed several methods based on deformable models [5, 6]. For accurate detection of neuro-retinal cup, Zhuo Zhang et al. [7] uses convex hull based ellipse optimization algorithm. This algorithm gives better cup to disc ratio values which help to find out accurate glaucoma diagnosis. Clinical evaluation is done for more than fifteen thousand patients from Singapore and Australia, which yields better results. Automated glaucoma classification system was developed by Bock et al. [8] using data driven approach. Two stage classification approaches is used for pattern recognition. To capture glaucomatous structures several image-based features were collected which are used to assess the damage of the optic nerves.

Hatanaka et al. [9] presented a new technique for identification of glaucoma utilizing a vertical CDR. CDR is calculated by applying vertical profile on the OD. Blood vessels are removed from the image to view the disk and cup clearly. Canny edge and threshold method are applied to identify the edge of the optic disc and cup area on the vertical profile. Khalil et al. [10] works on machine learning techniques for automatic glaucoma detection. For training and testing many classifiers are applied for spatial and frequency based features. The machine learning techniques used here are works on combination of features. These techniques have the ability to detect 85% glaucoma cases.

A new approach proposed by Raja et al. [11] by considering wavelet transformation features to classify glaucoma infected images from healthy eye images. For classification SVM classifier along with the radial basis function kernel is used. To check the algorithm accuracy tenfold cross validation is done.

Sparse dissimilarity coding method was proposed by Cheng et al. [12]. This method is used to find the glaucoma using cup to disc ratio. Segmentation of OD is done with the help of the combining results from three disc segmentation techniques. Circular Hough transform followed by active contour models is the first technique, next technique used here is super pixel based feature extraction and classification and the last technique used is ellipse fitting. Based on the best result of the three techniques further processing is done to assess the glaucoma. In the significant examinations, predicting models embedded with the characteristic features of glaucoma were developed. Al-though these models performed well, numerous issues stay to be examined so as to improve the clinical setting.

MousaAl-Akhras et al. [13] methodology was applied to a dataset of 106 retina images obtained from different hospitals. The new system automatically identifies the Glaucoma using Support Vector Machines technique with 100% specificity and 87% accuracy. Artificial Neural Network classified the images with 98% accuracy.

Shoba et al. [14] apply ML based tactics for glaucoma detection. Once the pre-processing is over canny edge detection algorithm is used for blood vessel segmentation. For computation of features finite element modelling analysis was conducted. These features are fed in SVM for classification task. The work is vigorous to noisy samples. In a recent method [15] called Glowworm Swarm Optimization technique was used to identify the optic cup. The frame work used is vigorous in finding the glaucoma but fails to find the CDR. A new frame work is presented by Qureshi et al. [16] to make out glaucoma lesions. By using pixel-based threshold and watershed transformation tactics identifies the OD and cup regions of the pre-processed images. Finally using the count of pixels of both disk and cup CDR is computed. This method work well for identifying the severity of the glaucomatous lesions but fails to perform well for the scale and rotation variations in the suspected samples. DL based frame work is introduced by Shinde et al. [17] to automatic detection and classification of glaucoma from the sample input images. Here, to identify the ROI Le-Net architecture is used. For segmentation of Disk and cup the U-Net framework is used. At the end classification is done by using SVM, NN, and Adaboost classifiers. This method realizes better accuracy in assessing the glaucoma in the images by combining SVM, NN, and Adaboost classifiers but the computation cost is high. Another better improvement method [18] uses DL-based framework namely DenseNet-201 used for automated identification of cup to disk ratio which in turn uses the identification of glaucoma. This idea gives computationally better results. But performance needs to be improved. Mask-RCNN method is intruded by Nazir et al. [19] to group OD and Cup from the input samples. To extract the predominant features from the input images DenseNet-77 was applied as a backbone in the Mask-RCNN later segmentation done by the frame work Mask-RCNN. The segmentation is well done in this method.

3. Methodology

The methodology used in this work composes of the following tasks.

- Image acquisition
- Pre-processing of images
- Extraction of disc area and ROI [cup)]
- Elicitation of geometrical features of both disc and cup
- Development of damage detection system
- Evaluation and validation of the system.

Figure 3 b. Sample Disc c. Sample Cup
a. Image with Glaucoma

3.1 Acquisition of glaucoma

Relatively a huge sample size of 650 fundus images all of them in a frame size of 3072×2048 were collected from different public domain databases which include ORIGA, DRIONS-DB, Drishti-GS, ONHSD, and RIM- ONE. This database so called was verified to pick the images of almost uniform resolution. In all, about 180 glaucomatous eye images were mined, after removal of noise; only around 100 glaucomatous images were available. Rest of them were discarded because the images shown eyes with glaucoma in its last stage. To have the uniform frame across all images, a frame size of 512×512 pixels was fixed. A segment of the gallery of images is presented in the figure 1.

Figure 1: Segment of Image database

3.2 Pre-processing

Pre-preparing of the images was done to remove the noises present in the images. Here four filters were tried in order to find out the best filter in terms of adequate removal of noise. Interestingly DBMF proved to be successful in removing the major portion of the noise. The success of this filter is attributed to impulse noise present in all most all images. So this paved the way for accurate detection, diagnosis and damage assessment.

3.3 ROI separation

The procedure adapted to extract OD and the cup, the method enunciated by A. Murthy and M. Madheswaran [20] has been used. The procedure is displayed in the workflow as shown in the figure 2.

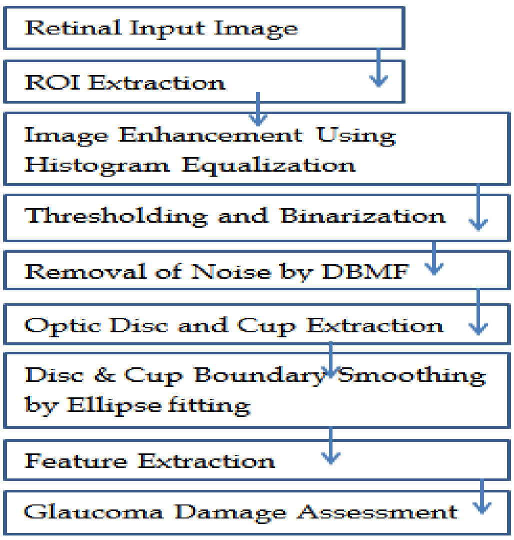


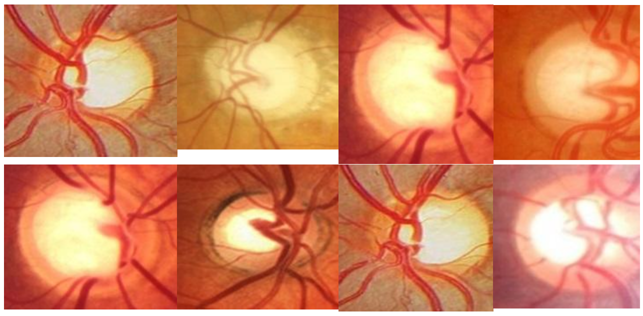
Figure 2: Work flow diagram

For the sake of completeness and clarity, a step by step procedure followed is in order.

i) As the OD occupies around 5% of the area in a typical fundus image. Added to this the area is usually of brighter color surrounding retinal area. Therefore 5% of pixels in the image with highest intensity are selected. 1511

ii) The retinal image is subdivided into 64 regions and approximate center of ROI is selected as a center of 64 regions

iii) Around this center a square is defined covering the brighter region and small portion of the surroundings. 1511



iv) The dimensions of the square were set to twice the OD diameter.

Table 1 sample data set

v) The segmentation of the OD is done using optimal color channel as determined by color histogram analysis.

vi) The disc boundary is carefully segregated from the retinal image.

vii) For cup segmentation, the convex hull method is used as per the procedure laid out in the reference [21].

The extracted portion of the disc and the corresponding cup from a particular image is shown in the figure 3.

3.4 Feature Extraction

Most of the reported research on glaucoma damage assessment cited in the literature indicates the CDR as the only parameter used to assess the degree of damage. But in this work the annular space that remains between the disc space and the cup space is measured. This is taken as a crucial feature because as the annular space becomes narrower and narrower the optical nerves are squeezed due to paucity of free space. This fact was also supported by ophthalmic surgeon during the discussions. Table 1 shows a sample segment of features.

Images	Disc Diameter	Cup Diameter	CDR	Annular Width	% constriction of annular space
Image1	395.86	304.05	0.77	46.56	23.1%
Image2	283.68	205.26	0.72	40.25	27.6%
Image3	312.47	195.30	0.63	62.83	37.5%
Image4	304.97	229.05	0.75	39.26	24.8%
Image5	354.05	109.26	0.31	133.11	69.1%
Image6	263.04	182.52	0.69	44.71	30.6%
Image7	285.04	97.76	0.34	106.09	65.7%
Image8	191.52	111.95	0.58	39.34	41.5%
Image9	477.06	320.96	0.67	70.72	32.7%
Image10	345.43	216.78	0.63	66.30	37.2%
Image11	390.88	157.13	0.40	115.37	59.8%
Image12	470.01	179.65	0.38	145.93	61.7%
Image13	188.06	145.55	0.77	24.03	22.6%
Image14	479.56	216.45	0.45	130.04	54.8%
Image15	428.32	296.32	0.69	64.14	30.8%

4. Damage Assessment Using Soft Computing

In this work soft computing techniques is proposed to find the severity of the glaucoma. Classification based on the severity is also made. Two soft computing techniques have been considered namely fuzzy inference system and back propagation neural network. The outcome of both the techniques is gradation of the given input image into either mild, moderate, sever and chronic kind of severity. While in FIS the output will be in the linguistic format and the neural network will do approximate grouping into any one of the labelled groups mentioned.

4.1 Fuzzy inference system

The three features namely CDR, annular space width and percentage of constriction were considered as antecedents for the development of FIS.

Rules	CDR	Annular space width	Percentage of constriction	Group (output)
1	3	1	2	2
2	1	2	3	1
3	1	2	3	2
4	1	1	1	2
5	1	1	3	1
6	1	1	3	1
7	4	1	4	3
8	2	3	1	2
9	3	1	4	4
10	3	2	4	3
11	1	1	4	4
12	2	4	4	3
13	1	1	3	3
14	1	3	3	2
15	1	1	4	2
Key :1 – Mild 2- Moderate 3- Severe 4 – Chronic				

The steps involved in the development of FIS are:

i) Fuzzification of the inputs in the form of grades (fuzzy membership functions) named mild, moderate, sever, and chronic.
ii) Development of fuzzy rule base
iii) Inferencing and arriving at the mapping
iv) Testing and validating the system so developed

Fuzzification: The inputs were fuzzified using triangular membership function. The function with function theoretic representation of MF is given by the equation

$$\mu_{A(x)} = \begin{cases} 0 & x \le a \\ \dfrac{(x-a)}{(b-a)} & a \le x \le b \\ 1 & x = b \\ \dfrac{(c-x)}{(c-b)} & b \le x \le c \end{cases}$$

Figures 4, 5 and 6 show the fuzzified linguistic variables for CDR, annular space width, and percentage of constriction respectively. Figure 7 outline the output membership function for different groups. A sample segment of fuzzy association map is shown in the table 2. Mamdani logic has been used in building fuzzy rules. In all, 120 rules were developed.
A fraction of fuzzy rules are shown in the table 3. A rule viewer is depicted in the figure 8.
Fuzzy inference: A portion of the database was used in order to build a robust fuzzy inference mechanism. For this, group of data was used and system was built and inferencing is done. The system so developed is checked using other fraction of the data. This procedure is repeated till the system graded the deterioration with adequate accuracy. Damage assessment using the developed system and the different degree of damages are shown in the figure9.

Table 2: Sample segment of Fuzzy Association Map

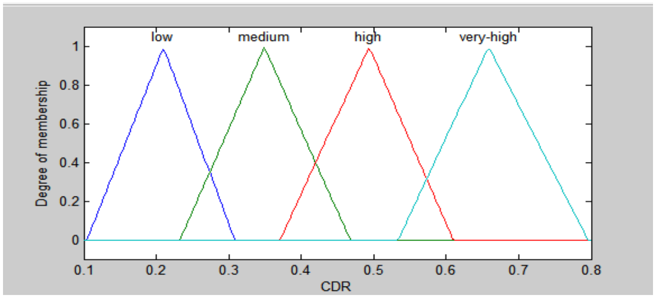


Figure 4: Input Membership function for CDR

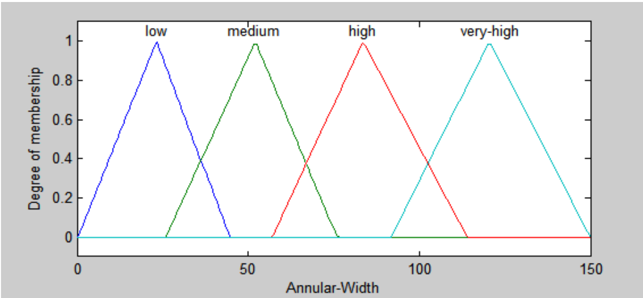


Figure 5: Input Membership function for annular width

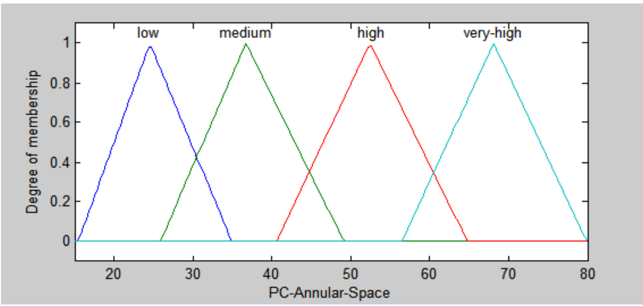


Figure 6: Input Membership function for Annular space

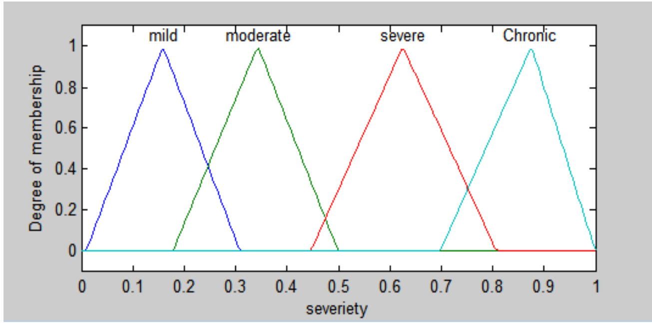


Figure 7: Output Membership function for grouping

Figure 4 – figure 7 shows the fuzzified version of the input features as well as output. For both inputs and output triangular memberships were considered for the fuzzy gradation of input features as well as severity. The reason behind selection of triangular membership function for both input and output are:

- Triangular member ship function provides an easy way for computation of defuzzified value.
- They provide simple linear monotonic function for the variation of membership values across the range of parametric values.

Table 3: Sample set of Rules

1. If (CDR is low) and (Annular-Width is low) and (PC-Annular-Space is low) then (severity is mild)

2 If (CDR is medium) and (Annular-Width is medium) and (PC-Annular-Space is medium) then (severity is moderate)

3 If (CDR is high) and (Annular-Width is high) and (PC-Annular-Space is high) then (severity is severe)

4 If (CDR is very-high) and (Annular-Width is very-high) and (PC-Annular-Space is very-high) then (severity is chronic)

5 If (CDR is high) and (Annular-Width is high) and (PC-Annular-Space is medium) then (severity is chronic)

6 If (CDR is low) and (Annular-Width is low) and (PC-Annular-Space is low) then (severity is chronic)

7 If (CDR is medium) and (Annular-Width is medium) and (PC-Annular-Space is medium) then (severity is severe)

8 If (CDR is medium) and (Annular-Width is medium) and (PC-Annular-Space is low) then (severity is mild)

9 . If (CDR is medium) and (Annular-Width is low) and (PC-Annular-Space is low) then (severity is mild)

10 If (CDR is low) and (Annular-Width is low) and (PC-Annular-Space is low) then (severity is chronic)

11 . If (CDR is low) and (Annular-Width is low) and (PC-Annular-Space is medium) then (severity is mild)

12 If (CDR is low) and (Annular-Width is low) and (PC-Annular-Space is low) then (severity is severe)

13 If (CDR is very-high) and (Annular-Width is high) and (PC-Annular-Space is medium) then (severity is severe

14 If (CDR is medium) and (Annular-Width is medium) and (PC-Annular-Space is medium) then (severity is moderate)

15 If (CDR is high) and (Annular-Width is low) and (PC-Annular-Space is high) then (severity is mild)

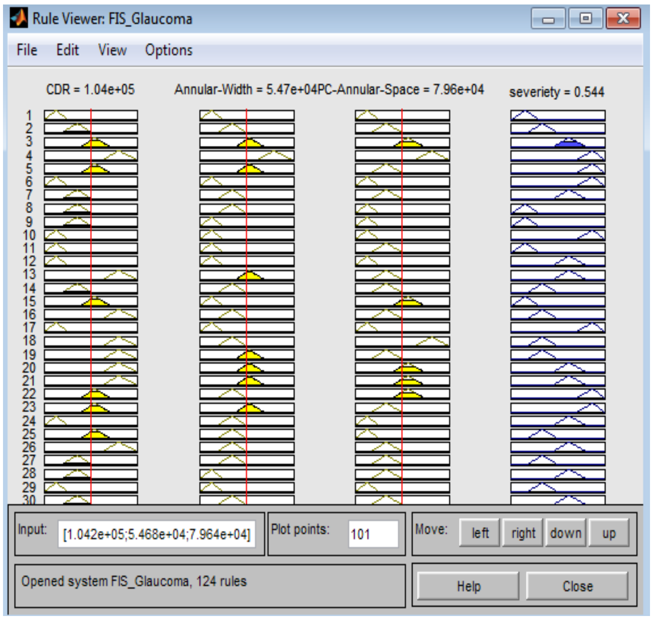


Figure 8: Fuzzy rule viewer

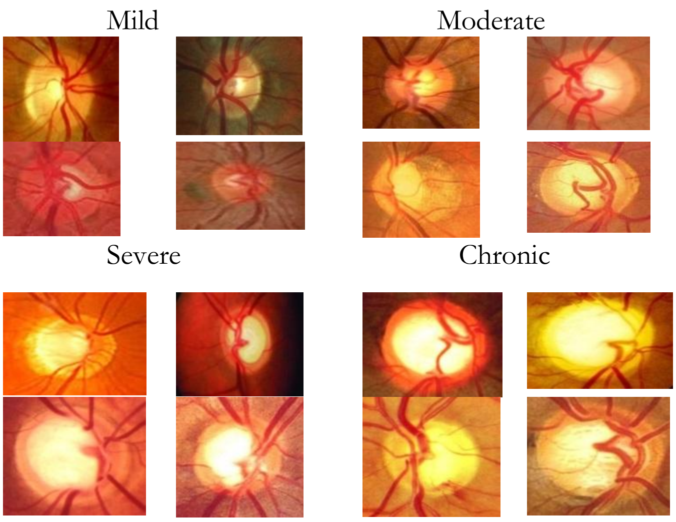


Figure 9 : Small segment of images in different groups as determined by FIS

4.2 Evaluation of the system

Evaluation of the system was made by using the same data which was used to develop the model (70% of the images). The evaluation results are given in the contingency table 4.

Table 4 : Contingency Table

	G1	G2	G3	G4
TP	15	14	11	09
TN	02	02	01	02
FP	01	01	02	01
FN	02	03	01	03

Evaluation metrics namely specificity, sensitivity and accuracy were estimated and presented in the table 5. From the table it is clear that the identification of true positive varies between 84% - 93%. Similarly identification of true negative is also adequate in the range of 75% - 91% as indicated by specificity. The overall accuracy of the system lies between 80% - 85%. This conclusively proves that FIS can be used as a tool in glaucoma assessment.

Table 5: Evaluation of the system

Groups	No of test images	Specificity	Sensitivity	Accuracy
G1	20	88%	93%	85%
G2	20	82%	93%	80%
G3	15	91%	84%	80%
G4	15	75%	90%	80%

4.3 Damage assessment using BPNN

As a second method under the ambit of soft computing technique BPNN was also implemented and a model is developed. To find the optimized BPNN model several combinations of central layers with varied numbers of neurons were tried during computational experiments. However a NN model with topology 3-9-1 evolved to be optimal during the evaluation of the network. The parametric details of the NN are presented in the table 6. The data of 100 images were grouped manually depending on the input features and those images were classified into 4 groups numbered as 1 to 4. The topology of NN is shown in figure 10.

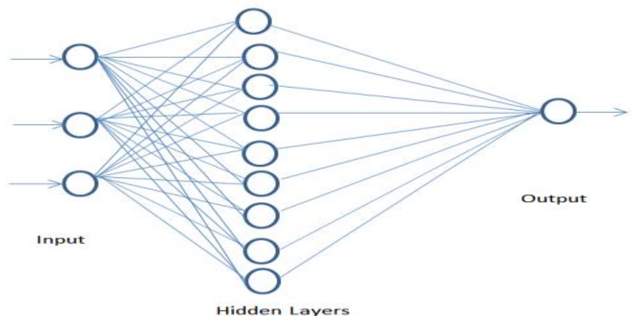


Figure 10: Network topology

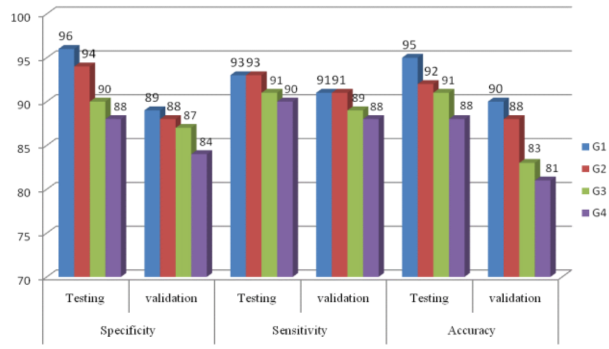


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Figure 11: of performance evaluation

4.4 Methodology

For training the network model 70% of the data were considered. Number of iterations was set as the stopping criteria. The testing of the NN was done using the same data used for training. The performance of BPNN during testing is shown in the table 7. It can be seen that the grouping accuracy is high for groups 1, 2, and 3. However the performance against group 4 is little low when compared to other 3 groups. The model so tested was also validated using 30% of the remaining data sets which were not used during the training of the model. The results of validation are presented in table 8. The metrics of evaluation of the NN model was found in terms of sensitivity, specificity and accuracy both for test set and validation set. The results of performance evaluation are presented in figure 11 in the form of bar chart.

Table 6: Salient details of BPNN Implemented

No of input layer neurons	3
No of neurons in hidden layer	9
The basis function	Sigmoid
Training function	Trainlm
No of output neuron	1

Table 7: Performance of BPNN Testing Mode

Groups	Degree	Actual severity	Correctly classified	% of classification
Group1	Mild	20	19	95%
Group2	Moderate	20	19	95%
Group3	Severe	15	14	93%
Group4	Chronic	15	13	86%

Table 8: Performance of BPNN validation Mode

Groups	Actual severity	Correctly classified	% of classification
Group 1	10	09	90%
Group 2	08	07	87%
Group 3	06	05	83%
Group 4	06	05	83%

5. Conclusions

This paper presented a part of the work which was directed towards the assessment of visual damage owing glaucoma. The outcomes of this work are in order:

i) This work has brought out two novel features in glaucoma inflicted eye namely, annular space width and percentage constriction of the annular space. These two features stand to be novel because huge literature survey cited in referential work has indicated that majority of the researchers have used only cup to disc ratio as the predominant feature.

ii) The design of automated system which is capable enough to assess the severity of the glaucoma in four degrees as mild, moderate, severe and chronic which are solely based on the range of input feature values.

iii) Application of soft computing viz., FIS and BPNN with three input parameters. While FIS was little low in accuracy when compared to BPNN which shows adequate accuracy in terms grouping.

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eISSN 1303-5150

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