Image Processing Techniques for Automatic Detection of Glaucoma - A Study

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***Abstract*--The review paper describes the application of image processing techniques for automatic detection of Glaucoma. Large percentages of people suffer from Glaucoma in rural and semi urban areas in India as well as world over. Image processing techniques greatly help to diagnosing Glaucoma. Glaucoma is dangerous eye disease causes permanent blindness when it is untreated in earlier stages. Until the disease reaches to an advanced stages it shows no symptoms hence regular eye test is very important. The automatic analysis involves using structural and texture features of retinal images. The key image processing elements to detect Glaucoma include image registration, fusion, segmentation, feature extraction, enhancement, pattern matching, image classification, analysis and statistical measurements. In developing and under developing countries large number of people are suffering from ophthalmic diseases like Glaucoma, Age related Macular Degeneration (AMD), Diabetic Retinopathy, Diabetic hypertension. A large deficit of ophthalmologists exists in these regions. Year after year the number of medical assistants is decreasing, while demand for healthcare is increasing and expected to touch 40% by 2020. The techniques mentioned in the present review have certain advantages and disadvantages. Based on this study, one can easily determine which technique provides optimum result.**

***Keywords*-- Glaucoma, image registration, fusion, segmentation, enhancement, Diabetic hypertension, Diabetic Retinopathy.**

I. INTRODUCTION

Glaucoma is a group of eye diseases with common characteristics that result in damage of human visual system. The changes occurred in retinal structures such as eye's optic nerve, which gradually lead to blindness or vision loss. Glaucoma is the second largest cause of blindness in the world. According to survey around 2.3% of the total population got affected by glaucoma and is predicted to affect around 11.1 million people (around 2.86%) by 2020 [1]. Among the retinal diseases 13% of cases being affected by glaucoma. One among 200 people aged 40 and one among 10 who age 80 are suffering from glaucoma.

Very dangerous thing about glaucoma is that it shows no symptoms in earlier stages, that is no pain, no vision change etc. If remain untreated, the patient may start losing his side vision. Gradually he/she feels like looking through a tunnel. Glaucoma is non reversible but can be controlled by detecting the disease in earlier stages. In advanced stages glaucoma patient usually shows thinness of the cornea, high eye pressure and abnormal optic nerve anatomy.

The main cause for glaucoma is increased intraocular pressure in the eye. To maintain healthy vision human eye produces a small amount of fluid called aqueous fluid or aqueous humour. It provides nutrition for various tissues. In normal eye amount fluid produced and amount of fluid thrown out of the eye are same. An imbalance is created in fluid flow when drainage system is blocked or eye produces an excess of fluid. This leads to increase in intraocular pressure. Due to high intraocular pressure optic nerve head and retina are progressively damaged and causes vision loss.

II. CLASSIFICATION OF GLAUCOMA

Based on how the introcular pressure increased glaucoma is classified as two types.

*(1) Open-angle glaucoma***:** This type of glaucoma is also called chronic glaucoma. It is most common type of glaucoma and symptoms are very slow to develop. It causes when an aqueous fluid is over produced or when eye drainage system is clogged over time. Due to this the fluid can't move out of the eye. This leads to increase of intraocular pressure. Its progression is very slow and patients can not notice their vision loss until the disease has increased significantly. More than 80% of glaucoma patients are suffering from open-angle glaucoma. This type of glaucoma usually responds well for medications, it can be detected easily and treated in earlier stages.

(2) Closed-angle glaucoma: This is also called as acute narrow angle glaucoma. It is very rare and very serious form of disease. Around 10% of glaucoma patients are affected by closed-angle glaucoma. Closed angle glaucoma occurs in the people who have very narrow space between cornea and iris. As the eye ages, the pupil grows this leads to blocking of this narrow space. Hence, fluid flow is restricted. This leads to rapid raise in intraocular pressure. Because of sudden increase in pressure inside the eye, this type of glaucoma is very painful. This also shows symptoms like nausea and vomiting. The closed angle glaucoma is treated by creating path for fluid flow between cornea and iris by surgery.

Different parameters are considered to detect glaucoma, based on these parameters glaucoma detection methods are classified into three types:

a) **Assessment of raised intraocular pressure (IOP):** In many cases glaucoma exist without increased IOP, in such cases IOP measurement technique fails to detect the disease.

b) Assessment of abnormal visual field: Visual field examination requires special equipment which is usually available only in tertiary hospitals, if they have a fundus camera and OCT (Optical Coherence Tomography). therefore this method is unsuitable for glaucoma screening.

c) Assessment of changes in retinal structure: In the inner surface of the eye, retina has light sensitive neuron layers. Eye diseases such as diabetic retinopathy, macular degeneration and glaucoma affect the neuron layer. Hence an eye retinal fundus images are analyzed for detection of glaucoma. There exist two central issues to glaucoma recognition using fundus images:

i. Texture feature extraction from the retinal images: use of image features (pixel intensity, textures, spectral features, parameters of histogram model etc) for a binary classification between glaucomatous and healthy subjects. These features are normally computed at the image-level. In these methods, selection of features and classification strategy is difficult and challenging.

ii. Structural feature extraction from the retinal images: this strategy is based on clinical indicators such as vertical cup-to-disc ratio, disc diameter, peripapillary atrophy etc.

High intraocular pressure in the glaucomatous eye damages the optic nerve head along with changes in different retinal structures. Various structural changes in retina are:

a. Optic nerve head variance: Optic nerve head is the location where all the optic nerve fibers are combined to form an optic nerve. This region does not have photoreceptors to receive the light entering into the eye and do not respond to the light hence it is also called as "blind spot". In 2-D retinal images optic nerve head is distinguished as a brightest yellow past with oval shape. It contains a central optic cup surrounded by an optic disc, as shown in fig 1.

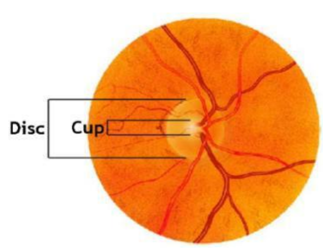


Fig. 1: Optic disc and optic cup in retinal images

When glaucoma occurs more optic nerve fibers disappear, optic cup size become larger. Change in the cup size is analyzed by taking cup-disc ratio (CDR). The ratio can be defined with respect to vertical diameter, horizontal diameter and area of both optic disc and optic cup. The CDR is used to compare glaucoma patients with normal one.

b. Neuroretinal rim loss: The region between the optic disc and optic cup is called neuroretinal rim, it contains neural elements. Fig 2 shows the characteristic patters of neuroretinal rim in normal images. Its length is not constant in all regions, it follows ISNT rule in normal eye. This rule says that the length of neuroretinal rim is more in inferior region followed by superior, nasal and finally temporal regions. In glaucoma patients neuroretinal rim will not follow ISNT rule.

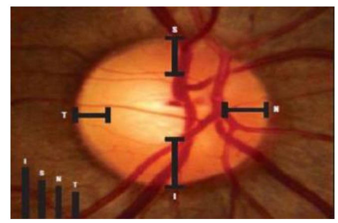


Fig. 2: Neuroretinal rim showing ISNT regions

c. Peripapillary Atrophy (PPA): PPA is an important factor for glaucoma detection. It is the degeneration of retinal pigments such as photoreceptors, epithelial layer and choriocappillaries in the region surrounded by optic nerve head.

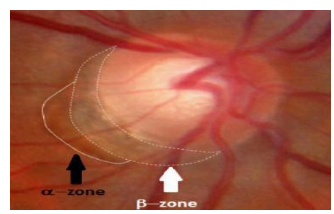


Fig. 3: PPA with α and β zones

As shown in fig 3, PPA is divided in to α and β zones. In normal eye both α and β zones are frequently located in temporal regions, inferior regions and superior regions. But, in glaucomatous eye β zone occurs more frequently in temporal regions.

This Paper is organized as follows. Section I explains the introduction to glaucoma. Section II describes the classification of glaucoma. Section III describes the glaucoma detection. Section IV describes various methods available for glaucoma detection. Finally, Section V presents conclusion.

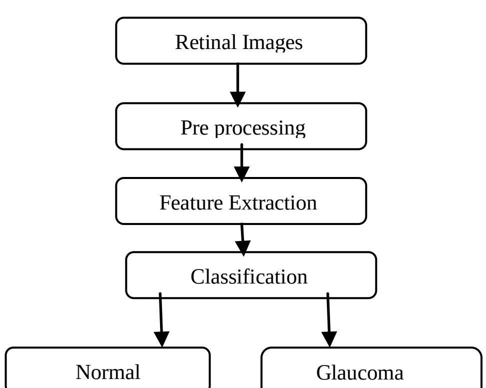
III. GLAUCOMA DETECTION

There are number of clinical methods are available for glaucoma detection, but population growth and raising levels of obesity causes the number of ophthalmologists needed for direct examination is a limiting factor. So a system for automatic recognition of characteristics of pathological cases would provide a great benefit. Many automatic methods are available for glaucoma detection. All these methods are based on the retinal changes occurred with the effect of disease.

One of the major glaucoma symptoms is that the cup area enlarges and occupied the most of the disc area. Many techniques are developed to identify the enlargement of optic cup. This is done by calculating the ratio of optic cup to disc area or ratio of cup-disc vertical diameter. Larger ratio indicates the occurrence of disease. However, evidences have proved that the physical detection and prognosis of glaucoma is quite laborious and subtle in nature and entirely depends on professional expertise. From the last few decades ginormous efforts have been done on detection and prediction of glaucoma using several Machine Learning techniques. Some of the techniques which have been used are neural networks, decision tree based on ID3 algorithms, Support Vector Machine, Naive Bayesian classifier, k- nearest neighbor, Canny edge detector, active contour model, linear regression, Fuzzy min-max neural network, K-Means Clustering, Thresholding, CDR and ISNT.

A. Process of Detecting Glaucoma Detection

To detect the glaucoma, initially, retinal images are capture using digital devices for image content. Then pre-processing is performed for equalizing and reshapes the irregularities on the images. In pre-processing, blood vessels are segmented and in painted to gain a vessel-free image. Then, Feature extraction is performed to reduce the dimensions effectively to represent the interested parts of an image as a concise feature vector for describing the large data set precisely. Pixel intensity values, textures, FFT coefficients and Histogram model are the methods used in feature extraction. Image Classification is performed which analysis the numerical properties of an image and organizes the data. Depending on the results obtained, the set of data is divided into discrete classes i.e. normal eye or glaucomatous eye. The general glaucoma detection process [2] is illustrated in Flowchart 1.



Flowchart I: Generic process for detecting the glaucoma [2]

B. Database used [3]

- Stare (around 400 images are available).
- Rim one.
- Drions-DB (around 110 images are available).

IV. SURVEY ON TECHNIQUES and ALGORITHUMS

There exist many techniques and algorithms for detection of glaucoma and validation. Optic Cup to Disc Ration [4] is one among the highly researched approaches followed by PCA [5], ISNT [6&7] based approaches for robust extraction and many such to discuss on this section.

A. Enhancement of Optic Cup to Disc Ratio

The optic cup to disc ratio is one of the principle physiological characteristics which is employed for detection of glaucoma. The C/D ratio represents the depression in the optic disc in which neural tissue is absent and compared with overall optic disc size. A larger C/D ratio has greater risk of glaucoma. Below are the various steps mentioned to determine the CDR as illustrated in flowchart II.

a) **ROI Determination:** Region of Interest (ROI) is the small portion of an image which has been extracted and necessary operations has been performed on it. By creating a binary mask, one defines an ROI as a binary image that has the same size as of the image we want to process. In the mask image, pixels which lie in ROI has been set to 1 and all other pixels has been set to 0. By this process, in order to extract the optic disc has been traced out as optic disc occupies less than 5% of pixels in retinal fundus image. By localizing the ROI, it reduces the computational cost and also improves accuracy of segmentation .it is defined as a rectangle around the ROI centre with dimensions of twice the typical optic disc diameter [4], and has been used as the initial boundary for the optic disc segmentation.

b) Optic Disc Segmentation*:* Segmentation of optic disc and optic cup eliminates the disadvantages of conventional Optic Nerve Head (ONH) evaluation methods. There are various techniques for segmentation based on template matching, machine learning, active contour model, level sets and Hough transform. For calculating the vertical cup to disc ratio firstly the optic cup and disc segmented from the retinal images [4].

c) Optic Disc Smoothening: The detection of disc boundary from the previous step might not have actual shape, since the boundary can have effect on blood vessels which are entering into the disc. Therefore, ellipse fitting has been applied in order to reshape the disc boundary [4].

d) Optic Cup Segmentation: Optic cup segmentation is bit harder than optic disc extraction since the cup-disc boundary is less measurable than that of disc region and besides combines with increased visibility of blood vessels across the cup-disc boundary.

e) Optic Disc Smoothing: After detecting the cup boundary, ellipse fitting is used furthermore to remove few boundaries of optic cup occurred due to sudden changes in the curvature. Ellipse fitting is an important tool especially when portions of the blood vessels in the neuro-retinal rim which is outside the cup are included within the detected boundary. Based on the height of detected optic disc and cup, the cup to disc ratio (CDR) has been obtained [4].

f) Ellipse Optimization for optic disc and cup: Ellipse fitting algorithm is used for smoothening the optic disc and cup boundary. Usually, Ellipse fitting is based on least square fitting algorithm which assumes that the best-fit curve has minimal sum of deviations squared from given set of data points (least square error). It allows fitting the ellipse on a certain data points in a particular region of interest.

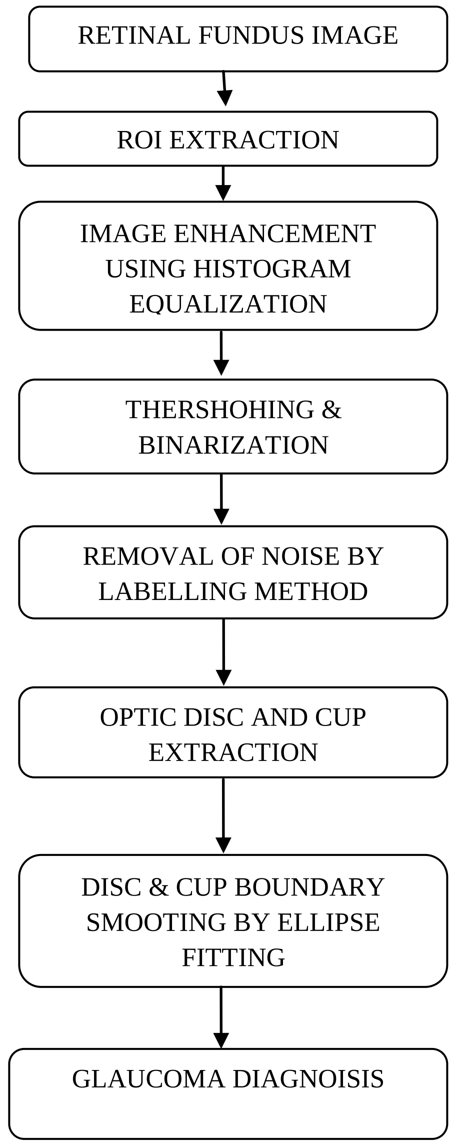
The risk of glaucoma has been predicted by CDR value; if CDR exceeds 0.65 indicates high glaucoma [4]. Thus by enhancing the CDR ratio might be used for diagnosis of glaucoma.

B. Glaucoma detection using PCA and Bayes Classifier

Principal Component Analysis (PCA) is the technique which is used for data reduction and to de-correlate the data [5]. Two applications has been done by PCA in image processing, first, the three components in a colour image has been reduced to one component containing a major part of information, second, calculating the eigen vectors corresponding to largest Eigen value to determine the features of an object in an image. Therefore, by this process PCA has been used for location of optic disc in retinal fundus images. Two strategies for retinal fundus image analysis has been proposed, one is bottom-up approach in which optic disc is identified by largest pixels having highest gray level image and second, top-el down processing to locate the optic disc automatically. These two approaches have been used for determining the candidate regions and PCA approach is used to find exact location of optic disc [5].

Bayes Classifier is based on Baye's theorem technique and it is more suited when dimension of the inputs is high. It classifies the objects in an image by considering their respective prior probabilities in an image. The proposed glaucoma classification process includes Retinal image pre-processing, calculating Eigen vectors from training images, Projecting the testing images to "disc space", and Distinguishing glaucoma with Baye's classifier based on Gaussian model.

The results obtained by this technique are given in table. I. Thus, by reducing the components or data in an image and by calculating the eigen vectors, the detection of glaucoma has been done [5].



Flowchart II: Glaucoma diagnosis using CDR Measurement [4]

TABLE I: Results of automatic glaucoma detection process

Input Image	Automated detection		Total	Success rate
	Glaucoma	Non-glaucoma		
Clinical Glaucoma	110	33	143	76.4%
Clinical Non-glaucoma	39	142	181	78.5%

C. Detection using CDR and ISNT ratio

It is to note that ganglion cells are scattered all over the retina, their fibres converge on the optic nerve head and layers of fibres get thicker just at their nerve head & piled up and dive into the opening. The nerve head is called as disc filled with fibres, and the left over space in the middle of nerve head is called cup shown in fig. 4 & 5. Comparing the size of cup to the size of whole disc is Cup to Disc Ratio (CDR) [6 & 7]. Due to increase in intra ocular pressure, the CDR increases due to rise in cup size. The CDR is reckoned to be less than 0.5 for normal optic disc but for abnormal optic disc, it exceeds 0.5.The increase in cup size also affects the Neuro-retinal Rim (NRR). NRR is the area located between the edge of the optic disc and the optic cup [8]. If glaucoma exists, ratio of area covered by NRR in nasal and temporal region becomes thick compared to the area covered in inferior and superior region. This method uses ONH [7] segmentation, based on morphological operations, Hough transform, and anchored active contour.

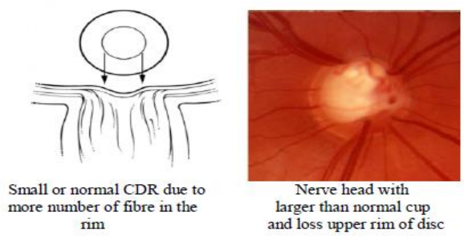


Fig. 4 [9]

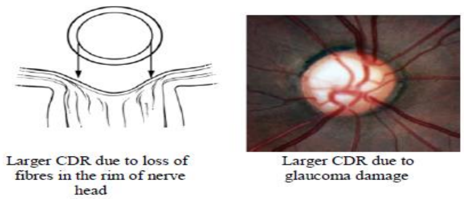


Fig. 5 [9]

This method has been demonstrated on 62 images and achieved specificity of 80% and sensitivity of 100%. Through K-means clustering, 95% accuracy has been achieved to extract the optic disc and optic cup region using Hill Climbing Algorithm and accuracy of 90% through Fuzzy C-Mean clustering for optic Cup.

ISNT Rule: ISNT means Inferior Superior Nasal Temporal. This rule is used for differentiating the normal optic nerve from glaucomatous optic nerve. For normal eyes, Disc rim thickness of Inferior > Superior > Nasal > Temporal. In fact the temporal rim being the thinnest is probably the most important, thus determines how optic nerve should be for a normal eye as shown in fig. 6.

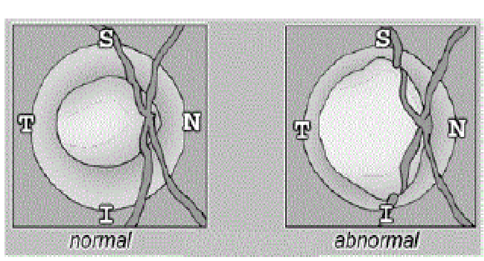


Fig. 6 [10]

Detection: For evaluating CDR and NRR ratio in ISNT quadrants, extraction of two features has been done by Mean Threshold Morphological method. Optic disc and cup has used for evaluating CDR and NRR ratio. CDR is calculated as

$$\text{CDR} = (\text{Cup area} \div \text{Disc area}) \text{ x } 2$$

Extraction of Neuro-retinal Rim: For extracting NRR, AND operation is applied on both resultant images of disc and cup. A mask of size 256x256 is applied on the extracted NRR image to measure the ratio of area covered by NRR in the ISNT quadrants. For determining ratio separately, Mask is rotated 90 degrees each time in ISNT quadrants. Accuracy is given as [11].

$$\text{Accuracy} = \frac{\text{Tp} + \text{Tn}}{\text{Tp} + \text{Tn} + \text{Fp} + \text{Fn}} * 100$$

Here Tp represents True Positive, Tn represents True Negative, Fp represents False Positive and Fn represents False Negative.

After performing evaluation results, accuracy is about 97.5% and 98.3%.

D. A Novel automated glaucoma detection

This system deals with the images procured from Stratus Anterior Segment Optical Coherence Tomography (AS-OCT). OCT [12] is a non-contact, non- invasive imaging technique that reveals layers of retina by looking interference patterns of reflected laser light. AS-OCT generates in-vivo, cross-sectional scans of tissue to analyze cornea, anterior chamber angle, lens and iris. AS-OCT is preferred since it produces quality images, captures at high speed rate and also has capability of determining depth of foreign body. To distinguish abnormal images from normal images, a Fuzzy min-max neural network based on Data-

Core (DCFMN) has been used. It has a strong robustness and has high accuracy in classification. DCFMN has two types of neurons: classifying neurons (CNs) and overlapping neurons (OLNs). CNs used to categorize the patterns of data. OLN handles all kinds of overlapped hyper boxes. The membership function of OLNs deals with relative position of data in hyper boxes. The performance of this method is excellent and classification rate of 97% has been achieved [12]. The mean deviation was -0.67 ± 0.62 dB in normal and - 5.87 ± 6.48 dB in glaucoma group. Using non-invasive imaging technique OCT and with the help of Fuzzy neural network based on DCFMN, glaucoma has been detected [12].

E. Automated glaucoma detection system having six different stages

The system [4] comprises Pre-processing, Region of Interest (ROI) Extraction, Feature Extraction stage, Calculation of CDR, Classification and Performance analysis stage. The system takes input as fundus image. In the pre-processing stage, illumination correction and blood vessel removal has been performed. After analysis of the entire image, a small square having 360 X 360 pixels taken around the brightest region denoted as ROI. Features have been extracted from optic disc and optic cup and CDR is calculated. The accuracy of classifiers namely SVM, Back Propagation Neural Network, ANFIS obtained are 98.12%, 97.35% and 97.77% [13]. From above six stages and by suitable classifier, one might get good accuracy in glaucoma detection.

F. Using z-score normalization technique

Another method developed as an automated glaucoma detection system by combining the texture and higher order spectra (HOS) [14] features obtained from fundus images. Naive Bayesian, Support vector machine, random-forest classifiers and sequential minimal optimization has been used to perform the classification. After z-score normalization and feature selection, the result gives the texture and HOS based features. When these features are combined with a random-forest classifier it performed much better than the other classifiers. This method has diagnosed the images of glaucoma with accuracy of 91% using HOS technique and with the help of random-forest classifiers.

G. Glaucoma screening technique using super pixel classification

This method [15] involves developing glaucoma screening technique using super pixel classification on optic disc and optic cup segmentation. In this method, each optic disc image has first over segmented into super pixels then, from each super pixel, mean intensities, centre surround locations and features of the location has been extracted in order to classify whether it is a cup or non-cup.

In optic disc segmentation, histogram has been used to differentiate each super pixel as disc or non-disc. A database consists of 650 images were used with boundaries of optic disc and optic cup. It showed an over-lapping error of 9.5% and 24% in optic disc and optic cup.

H. Glaucoma Detection without segmentation

An automated glaucoma classification system [16] that doesn’t depends on the segmentation measurements. In this method, image based features have been provided which are used to detect the glaucoma. This is based on evaluation of data and not on outline of optic disc and analyzing different types of features such as pixel intensities, spectral features, textures and parameters of histogram model. Three different classifiers has been used which are naive bayes classifier, k-nearest neighbour and Support Vector Machine (SVM). This algorithm took a standard pattern recognition approach. In this method, a feature of images has been analyzed and integrates to capture structures of glaucoma. In pre- processing phase, variations of size differences, illumination in homogeneities and structures of vessel has been removed. This system has 86% success rate of 200 real images for two stage classification with SVM.

I. Artificial Neural Networks in retinal image analysis

The wavelet transform [17] are used to extract the features like energy signatures from retinal image and using wavelet filters like db3 (daubechies), sym3 (symlets), (bi-orthogonal) rbio3.3, rbio3.5, rbio3.7, the wavelet features are evaluated and classifiers are trained using these values. The work could successfully detect whether the given retinal image is affected with glaucoma or not, using random forest, SMO, SVM, naïve bayes and ANN classifier using the classified values for wavelet features obtained. The probabilistic neural network found to be better than SVM, SMO, naïve bayes and random forest classifiers in detecting 75 glaucomated and 75 normal retinal images when accuracy, precision, sensitivity and specificity measures are considered.

IV. OVERVIEW

The overall methodologies mentioned above are listed in a tabular form and thus one can determine which technique can be applied to have an optimum result.

TABLE II: Different methodologies used for diagnosis of glaucoma

METHOD	PRE-PROCESSING TECHNIQUES	CLASSIFIER	SUCCESS RATE	REFERENCES
Ellipse fitting method	Noise removal, ROI extraction	Depends on value of CDR	86%	[4]
PCA	Top-down and bottom-up processing	Bayes	75-80%	[5]
CDR ISNT Rule	ROI extraction	K- means clustering Fuzzy C- means	95% 90% 97.5% & 98.3%	[6] [8] [9] [11]
Images from OCT	ROI extraction	Fuzzy min-max Neural network(NN) based on DCFMN	97%	[12]
Automated glaucoma detection	Illumination correction & blood vessel removal	ANFIS SVM Back Propagation	97.7% 98.12% 97.35%	[13]

Combining Texture and HOS	Z-Score normalization	Nave Bayesian, SVM, Random- Forest	91%	[14]
Super –pixel	Data-driven approach	Histograms	Error of 9.5%in optic disc and 24% in cup	[15]
Without segmentation	Pattern recognition	SVM	86%	[16]
ANN in Retinal Image Analysis	image texture	SVM SMO Random forest Naïve bayes ANN	92% 90% 91% 92% 98%	[17]

IV. STUDY OUTCOME

Based on study conducted, a details view on various techniques, algorithms and approaches has been studied and analyzed with respect to performances, evaluation and validation ratio, spoofing ratio of detection and much more. Technically, a growth in research observed in glaucoma detection from early 2000 and an elevated peak of research is observed on the introduction of cup to disc ratio.

Typically, a band of research prefers Cup to Disc ratio (CDR) is a key indicator for the detection of glaucoma. The existing approaches determined the CDR using manual threshold analysis which is fairly time consuming. Researchers proposes two methods to extract the disc automatically. The component analysis method and region of interest (ROI) based segmentation is used for the detection of disc. For the cup, component analysis method is used. Later the active contour is used to plot the boundary accurately [18].

Future, a new framework for glaucoma progression detection has been proposed glaucoma is classified by extracting two features using retinal fundus images. (i) Cup to Disc Ratio (CDR). (ii) Ratio of Neuroretinal Rim in inferior, superior, temporal and nasal quadrants i.e. (ISNT quadrants) to check whether it obeys or violates the ISNT rule. This novel technique is implemented on 50 retinal images and an accuracy of 94% is achieved taking an average computational time of 1.42 seconds [19].

For the glaucomatous image, the energy levels extracted using wavelet subbands Daubechies (Db4), Symlets (sym4) and Biorthogonal filters (bi03.7, bi04.2 & bi04.7) gives the clear indication of difference in the energy levels compared to that of normal retina image. The ANN algorithms Naive Bayes and MLP-BP are trained with normal retina images and classifies input image into normal or abnormal by considering extracted energy levels. Naive Bayes classifies the images in the database with the accuracy of 89.6%. MLP-BP ANN algorithm classifies the images in the database with the accuracy of 97.6%. This system exhibits better accuracy compared to existing glaucoma classification systems [17].

V. PROTOCAL DESIGN

Based on the study conducted, a texture and structural details of glaucoma detetcion are studied. In near future, with the help of these techniques, we need to develop some less expensive automated technique in order to detect glaucoma disease accurately.

VI. CONCLUSION

The damage done by glaucoma is irreversible. Early detection and treatment of glaucoma is the only solution, in this article, a brief and structural study is performed on selected cores of focused research outcomes for improving the in near future. Study focus on independent feature dependencies on contributory research for performance estimation and evaluation. These techniques would be helpful for less developed countries where there is a shortage of ophthalmologists. In future, accurate detection with less cost effectiveness, it may be beneficial to the poor people. Once glaucoma is correctly diagnosed there is a probability of avoiding total blindness.

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