



AN AUTOMATED METHOD FOR DETECTION OF GLAUCOMA USING IMAGE PROCESSING TECHNIQUES ON RETINAL IMAGES

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Abstract-

Glaucoma, a progressive optic neuropathy, is a leading cause of irreversible blindness worldwide. Early detection and timely intervention are critical to prevent vision loss, making automated glaucoma detection systems indispensable. This paper presents a comprehensive approach to glaucoma detection using advanced imaging techniques and machine learning algorithms. Our methodology involves the extraction of relevant features from retinal images, including optic disc cup-to-disc ratio, retinal nerve fiber layer thickness, and other clinically significant parameters. These features serve as input to a well-trained machine learning model, to classify images as either glaucomatous or non-glaucomatous. Validation of the proposed method is conducted on a diverse dataset comprising images from multiple sources, including different ethnic groups and varying degrees of glaucomatous severity. The results demonstrate the efficacy of our approach, achieving high sensitivity and specificity levels in glaucoma detection. Our automated glaucoma detection system offers a promising solution for early diagnosis, enabling timely intervention and management. This research contributes to the ongoing efforts to combat glaucoma-related blindness, emphasizing the importance of leveraging advanced imaging technologies and machine learning in the field of ophthalmology.

Keywords:

Retinal images, image enhancement, Segmentation, blood vessels extraction, feature extraction, cup to disk ratio, Glaucoma.

1 Introduction

1.1 Glaucoma

In world, there are more than 80 million patient of Glaucoma. It is the second cause which is responsible for world blindness.[10] In India more than 12 million case of Glaucoma is found. It is the one fifth of the existing world blindness due to this disease. Glaucoma, a group of eye disorders characterized by damage to the optic nerve, is a major global health concern and a leading cause of irreversible blindness. The optic nerve plays a crucial role in transmitting visual information from the eye to the brain, and when it becomes damaged, it can result in gradual vision loss. What makes glaucoma particularly challenging is its insidious nature—often progressing without noticeable symptoms until significant damage has occurred. The primary risk factor for glaucoma is elevated intraocular pressure (IOP), which can compromise the optic nerve's integrity. However, glaucoma can also develop in individuals with normal IOP, suggesting the involvement of additional factors such as vascular, genetic, and environmental influences.

Glaucoma is eye disorder which is occurring due to damage of optic nerve cells called ganglion cells. It is non- curable and irreversible process. This is happen due to the increased intraocular pressure. But some cases is observed that Glaucoma occur in normal and low eye pressure. So the evaluation of the optic nerve head can be an important factor for Glaucoma diagnosis. The Aqueous Humor is clear watery fluid which circulates through the front chamber of the healthy eye. The main function of the aqueous humor is given below.

It nourishes the area around the coloured iris.

It maintains the shape of the eye by exerting pressure.

This aqueous fluid causes a pressure known as intraocular pressure (IOP). As this intraocular pressure increases then the risk of the Glaucoma also increases.

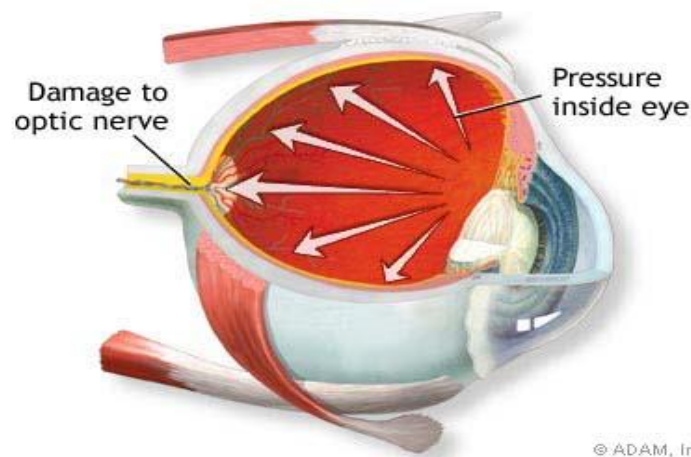


Fig. 1 damaging of the optic nerve head: this figure explains that how optic nerve head gets damaged due to intraocular pressure.

This aqueous humour gives the oxygen and the various nutrients to the lens and corena through drainage canals. When these canals get blocked then the intraocular pressure increased. Due to This increased pressure the optic nerve fiber get damaged. This results in the enlargement of the cup which leads to the loss of vision. This is the main cause for the glaucoma. There are the various factor which responsible for the Glaucoma. On the basis of these factors, the types of Glaucoma are as following.

1. Primary open angle Glaucoma
2. Primary closed angle Glaucoma
3. Congenital Glaucoma
4. Normal tension Glaucoma

PRIMARY OPEN ANGLE GLAUCOMA

Primary open-angle glaucoma (POAG) is the most common form of glaucoma, accounting for a significant proportion of glaucoma cases worldwide. It is characterized by a gradual and insidious progression of optic nerve damage, often leading to irreversible vision loss. POAG is asymptomatic in its early stages, earning it the moniker "the silent thief of sight," as individuals may not be aware of the condition until significant visual impairment occurs.

Key Features of POAG:

Open Angle: Unlike some other forms of glaucoma, POAG is characterized by an open drainage angle within the eye. The drainage angle refers to the area where the cornea and iris meet. In POAG, the drainage angle remains open, but there is a gradual reduction in the outflow of aqueous humor, the fluid that nourishes the eye.

Increased Intraocular Pressure (IOP): Elevated intraocular pressure (IOP) is a primary risk factor for POAG. The exact mechanism linking elevated IOP to optic nerve damage is not fully understood, but it is believed that increased pressure may compromise the optic nerve's blood supply and induce mechanical stress on the nerve fibers.

Optic Nerve Damage: The hallmark of POAG is progressive damage to the optic nerve, which is responsible for transmitting visual information to the brain. This damage typically occurs in the peripheral vision initially, and if left untreated, it can advance to affect central vision.

Risk Factors: Age: POAG is more prevalent in individuals over the age of 40, with the risk increasing with age. Family History: A positive family history of glaucoma increases the likelihood of developing POAG.

PRIMARY CLOSED ANGLE GLAUCOMA

Sometimes there is suddenly rising in pressure that results iris pushed against the lens. Due to which the drainage angle become closed. The following symptoms may be possible. Primary closed angle glaucoma may be chronic or acute type. In chronic type is less common condition and it is a gradual process. This process is painless. In acute type the following symptoms can be occurring.

Patients may feel pain in the eyebrow region.

Patients may have blurred vision with one eye.

Patients feel that his eye will burst.

Closed angle Glaucoma is more effective in Asians in compare to American.

NORMAL TENSION GLAUCOMA

In such cases found that intraocular pressure is normal but the some other factors are present. These factors damage the optic nerve. These factors do not affect the intraocular pressure.

CONGENITAL GLAUCOMA

This type case has a very rare chance to occur. This type of case is present from the birth. In such cases, drainage canals fail to develop in correct way. One baby has this type of Glaucoma from 10000 babies. Such cases can be improved with microsurgery.

1.1.1 HOW THE IMAGE IS FORM

It can be understand by the following procedure. This procedure will define the how the eye processed the light.

- The process begins with light entering the eye through the cornea, the transparent front part of the eye. The cornea helps focus light onto the lens.
- The lens, located behind the cornea, further refracts or bends the incoming light to focus it onto the retina at the back of the eye. The lens adjusts its shape to fine-tune the focus, a process known as accommodation.
- The lens converges the light rays, forming a focused and inverted image on the retina. The inverted image is a consequence of the optical properties of the lens.
- The retina contains specialized cells known as photoreceptors—rods and cones. Rods are responsible for vision in low-light conditions, while cones contribute to color vision in bright light. These photoreceptors convert light energy into electrical signals.
- When light strikes the photoreceptor cells, it initiates a process called phototransduction. This involves the conversion of light energy into electrical signals, which are then transmitted to the brain for visual processing.
- The electrical signals generated by the photoreceptors are transmitted through the layers of the retina to the optic nerve head. The optic nerve is a bundle of nerve fibers that carries visual information from the retina to the brain.

1.1.2 CASUSES FOR GLAUCOMA

Glaucoma is a complex group of eye disorders characterized by optic nerve damage, often associated with elevated intraocular pressure (IOP). The exact causes of glaucoma are not fully understood, and the condition can result from a combination of genetic, environmental, and physiological factors. Here are several factors associated with the development of glaucoma:

- Causes for Primary Open Angle Glaucoma: the rear reason is unknown. But most of the cases found due to the damaging the optic nerve head. Mostly the optic nerve is damaged due to the intra ocular pressure. But there are some reasons which also responsible for damaging the optic nerve.
- Causes for Primary Open Angle Glaucoma: closed angle Glaucoma is occurring due to structural defects. This create narrow angle between the iris and cornea. The aqueous humor circulates form this angle which increases pressure.
- Causes For Secondary Glaucoma: when the Glaucoma is occur due to some other reasons then it is called the secondary Glaucoma. Both open angle and closed angle Glaucoma is possible in this case.

1.1.3 RISK FACTORS

- Glaucoma is the second cause for the world blindness. It is estimated that there are more than 60 million cases worldwide. More than 12 million cases found in India. It is more effective for aging society. There are following risk factors.
- Intraocular Pressure (IOP): this is the main causes for the Glaucoma. Due to IOP the optic nerve cells become dead.
- Age: it is has a more risk factor for the aging society. Everyone has risk after the age of the 60 years to have the Glaucoma.
- Race and Ethnicity: Asians has the greater risk of the Glaucoma in compare to the African and American.
- Family Back Ground: If the family members have the Glaucoma then it increases the risk 5 times more than a normal patient in the age of 70 years.
- Medical Condition: If the patients have disease like the diabetes then it increases the risk factors for Glaucoma. So the patients having medical condition must take extra care of his eye. Some time high blood pressure also increases the chances of the Glaucoma. High doses of the medicine can be also increases the risk of Glaucoma. Wrong surgery of the eye also can be possible cause for the Glaucoma. So at the time of treatment of this type of diseases we should take care of our eye.

1.1.4 DIAGNOSIS OF GLAUCOMA

Glaucoma affected eye has no early symptoms so its screen is difficult. During screening we can find the damaged optic nerve. Glaucoma causes the irreversible damage of the optic nerve so the early detection is very important. Routine check up may be more helpful in screening the effect of the increase intraocular pressure. So with the help of routine check up of eyes may reduce the effect of the Glaucoma and it can be detected in early stage of the Glaucoma. However its treatment may have harmful effects. It is recommended that people less than 30 years must go for routine check up of Glaucoma. So in case of Glaucoma early detection is the key of successful prevention from blindness because Glaucoma is irreversible process.

Clinical Examination for Glaucoma Treatment: There are the following four types of test is done for the Glaucoma detection and to check the progression of Glaucoma.

To measure the intraocular pressure (Tonometry)

Test to check the visual field (perimetry)

To check the optic nerve head (ophthalmoscopy)

For evaluation of the drainage angle of the eye(Gonioscopy)

To measure the Cornea thickness(pachymetry)

To Measure the Intraocular Pressure (Tonometry): Tonometry is a painless process in which doctors measures the intraocular pressure of aqueous humor fluid. In this process, pressure is calibrated in millimetre in mercury. There are the following methods are available for this test.

In schiotz process, one drop of anaesthesia is given on the eye surface for numbing the eye. After numbing the eye, doctor placed a instrument into cornea. This instrument has a plunger which is intended to the cornea. We measure the pressure on the bases of that how much cornea intended on the given weight.

In Goldman method, in this process a special type of probe is used to measure the pressure and a microscope is used to examine the eye. The basic principal is how much weight is needed to flatten the cornea. In this process, anaesthesia is used to numb the eye and a dye is used to make easier to visible the cornea.

We can also use the non contact method of pressure measuring. In this process we do not use any eye drop to numb the eye. We focus a bright light into the eye and measure the reflection. On the basis of the measured reflection we estimate the pressure that how the reflected light changes. Air is also blown in this process. But the pressure measuring process is not so good in determining the damaging of optic nerve head. Some time the pressure does not results in damage of the optic nerve head. In some cases, on normal pressure the glaucoma is occurring.

Test to Check the Visual Field (Perimetry): If the doctor gets some clue that there is damaging of optic nerve head then doctor evaluate the visual field. This test is done for the check of peripheral vision. The doctor has a great interest in area related to the peripheral visual fields in glaucomatous eye. This process is done with the help of the computer aided software.

To check the optic nerve head (ophthalmoscopy): There are the several instrument is developed to measure the early damage of the optic nerve head. In this process we check the optic disc and the optic cup to measure the risk of the Glaucoma. In this process we take the fundus images of the eye. Other instrument is also available which use the lasers and computers. On the basis of performed examination, none of the test is proved accurate for the Glaucoma detection. Doctor measures the colour and shape of the optic nerve head for the evaluation of the disease.

To Measure the Cornea Thickness (Pachymetry): cornea thickness can be an important factor that is very helpful in evaluation of the progression of the disease. In this process, after numbing the eye an ultra sonic wave instrument is used for measuring the thickness of the cornea.

For Evaluation of the Drainage Angle of the Eye (Gonioscopy): By this process, they measure the angle between the eye's cornea and the iris. For this they used a gonioscopes with the help of the microscope. With the help of this process we can diagnose the various eye condition related to the Glaucoma.

Time for the Treatment: Glaucoma is a non curable disease, so early detection is very important for this disease. We cannot completely cure this disease. But the progression of this disease can be halt or slow down. Most of treatment is focused on the reducing the intraocular pressure. So the treatment may be surgery or medicine or both can be used to halt or slow down the progression of damaging the optic nerve. So the damaging of the optic nerve can be halt or slow down with the early detection.

In slow damaging of the optic nerve take time to become Glaucoma. So doctors advice the patients after conforming the clear issue of the damaging of the optic nerve. So the patients can start the treatment. If the optic nerve damaged than no treatment can repair this damage. So the treatment should be done with carefully. Some type of the drugs reduces the intraocular pressure from eye. However these type of drug also have side affect which can also damage the some other organ of the body. Patients can also go for the surgery. Surgery is done to reduce the pressure by increasing the flow of the aqueous humor. Filtration surgery and laser trabeculepasty are the two methods for surgery. Surgery is last option of the treatment. Both are effective surgery. While the patient is taking the dose then patients must be careful with his dose of drug. Skipping of doses may increases the risk of Glaucoma more than 5 times.

Shaibal Bhartiya(1010) has described the Glaucoma in depth. It describe the Glaucoma is occur due to change in intrapapillary and parapapillary region of the optic nerve head [1]. In this paper he describe that how the some factors get change due to the Glaucoma. Optic nerve head (ONH) and retinal nerve fiber layer has very good speciation and description. So we can evaluate these parameters by the following way.

Qualitative analysis

1. Neuroretinal rim's contour

2. Hemorrhages of optic disc
3. Atrophy of parapapillary
4. How the retinal nerve fiber layer appear

Quantitative Evaluation

1. Size of the optic disk
2. Ratio of cup to disk
3. Height of the retinal nerve fiber layer

This paper describes that how the radius changes in American, African and Asians etc. It describes the different stages of the Glaucoma. Closer the value to 1 is the worse the damage.

2 Description of Retinal Image and image processing

2.1 Fundus Camera

It is a special camera which has a low power microscope and a camera is attached to it. This camera captures the photographs of interior surface of eye which consist of a details of retina, blood vessels, optic disk, optic cup etc. it gives the coloured detail image of eyes. These coloured images are called fundus or retinal images. These retinal images are used in as input for the detection of the Glaucoma. These images are used for the feature extraction.

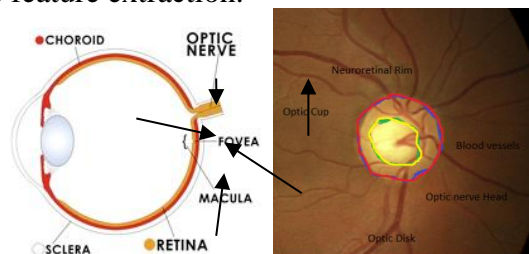


Fig.2 Different terms in retinal image and region of interest.

The above figure shows the various region of interest in the retinal image. It shows the optic disk, optic cup, Neuroretinal Rim, Blood vessels in the retinal image. The definition of these parts are as following.

- **Neuroretinal Rim (NRR):** it is defined as the region between the cup boundary to the disk. This region mainly consists nerve fiber. Rim thickness to disk diameter is known as Rim disk ratio.
- **Optic disk:** It is brighter part in the retinal image which is elliptical in shape.
- **Optic Cup:** It is the orange pink rim in the center of the optic disk.
- **Macular Region:** It is the pigmented area at the center of retina. It is oval shaped.

For the detection of the Glaucoma, there are the following changes occur in the eye.

- Area of the optic cup increases
- Damaging of the blood vessels
- Damaging of retinal surface
- Optic nerve head damaged

There are the following difficulties associated with the segmentation.

- Background of the retinal image is not homogenous.
- Width of the blood vessels is varying continually.
- Brightness of the retinal surface is not equal.

Due to all these difficulties, pre-processing of the retinal image is very much important before the segmentation.

2.2 DIFFERENT ASPECTS OF IMAGE PROCESSING

In this section I have described the image processing task in detail. Layout for the task is given below. This task can be completed in four stages. These stages are given below.

Acquiring the image: We know that a computer is able to process the digital images only. So In the First stage, we produce a digital image which can be processed through the computer. So we use a camera or scanner which changes the paper image to digital image.

Pre-processing: In this stage the processing part is done. Image processing can be defined as the making change in the image so the image can be enhanced in such a way that the image can be used in two way which is given below.

We try to improve its pictorial information for enhancing visual for better human interpretation. It will increase the pictorial information for better presentation of the image.

Enhancing the image in such way that it is most suitable for the machine application. We focus to improve the image in that information that is more suitable for autonomous machine application.

Segmentation: Segmentation is defined as the re-grouping of an image into their individual entities. By this process an object is differentiated from its surrounding in an image. Image segmentation is used when we want the process the only part of the image not the whole image. Image segmentation is very useful when we our region of interest is only in some region.

Representation and description: in this stage we extract the feature form the processed image. For these features we analyze the image for the conclusion. With the help of feature extraction, we can differentiate one object from the other objects. Here we try to extract some feature which related to the shape, size or the colour of the object.

Recognition and interpretation: in this stage we try to inter-relate the results and the features which I have been extracted from the mages. And we try to find the result of the processing. Stage may involve some arithmetic operations. This stage will solve the purpose of the processing.

3 Detection Process of Glaucoma

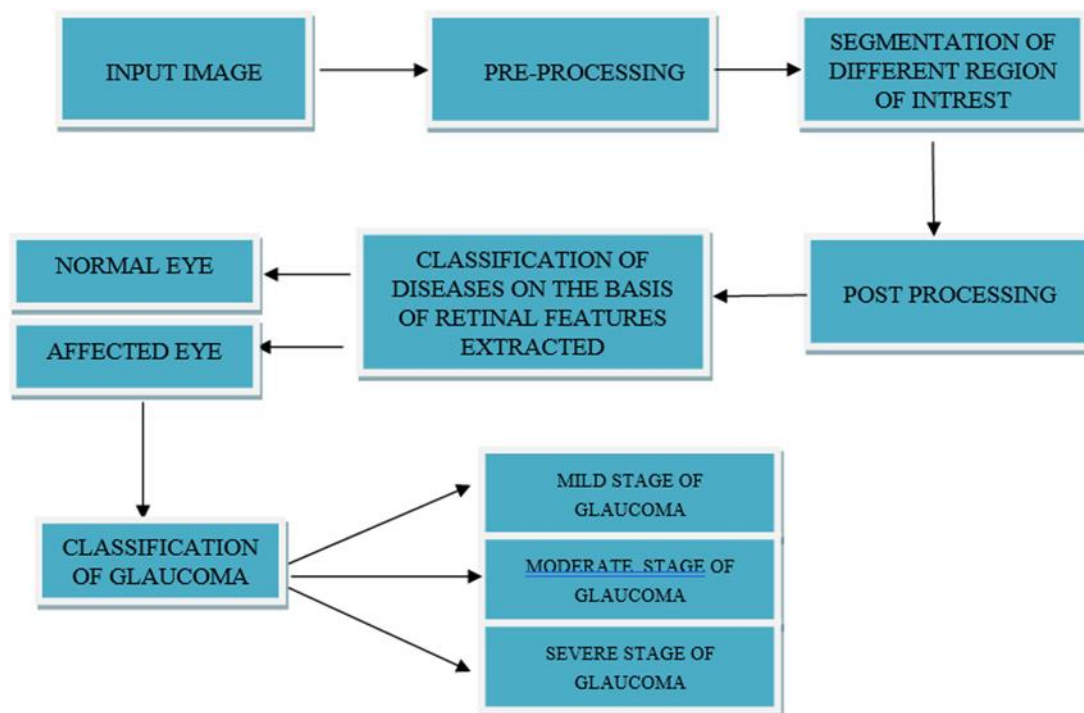


Fig. 3: Flow chart showing detection process.

K Sai Deepak (2012) describes the automated method of global feature extraction [2]. With the help of image representation we can devise to accentuate subtle indicators of the disease. The Global feature can differentiate between normal and Glaucomatous eye. This method first extracted region around the optic disc. Then the representation of the image is improved so that resulting image is more

meaning- full for the classification. In next step he transformed the spatial extent of intensities of corresponding to the interest of the signal in the retinal image. And from this image they extracted the Global feature for the classification. They used one classifier to learn feature subspace for normal case and then they used new image for classification. They list the visual indicators of this disease and they extracted the global feature using these indicators for classification.

Laszlo G. Nyul (2009) finds that the eye image back ground not provides the information about visual system but it also provide important information about the healthiness of the entire body [3]. So the retinal image analysis becoming the important part of the disease detection. They devised the automatic method for the mass screening of the patients. They derived the novel method for the classification of the Glaucoma on the basis of the image feature. In their data driven approach the need to correct the non uniform illumination, size differences and blood vessels elimination. They compressed the features vectors by PCA and then combined with SVM. They compared their results with human experts.

Fengshou Yin and Jiang Liu (2012) find that Vertical cup to disc ratio can be an important factor for the Glaucoma diagnosis [4]. They proposed a statistical based model for the segmentation of the optic disk and the optic cup from the colour retinal images. They used the circular hough transform and a method for the selection for the optimam image for segmentation. They extended the method for the cup segmentation. They calculated mean absolute CDR error rate. They have made the computerized automated method for the mass screening of the patients for glaucoma detection.

Riidiger Bock, jorg Meier and Georg Michelson (2007) proposed a method that extracted the different features form the colour retinal images [5]. The proposed method is not depended on the segmentation based method. Their approach is based on data which is collected from the fundus images. They apply two stage classifications which are based on the feature extraction. They have done the pre-processing to optimize the image. These are the following.

- Illumination correction
- Size differences
- Vessel elimination
- Enhancing the area of interest in the colour retinal images

After the following improvement they got the intermediate image. Form this image; doctor can also get the new vision for understanding the glaucoma disease. They achieved the 86 % susses rate. For data collection they calculated the following parameters.

- Pixel intensity Values
- Textures
- FFT coefficients
- Histogram Model

They used the Native Bayes Classifier and K-Nearest Neighbour Classifier for the Classification purpose. They used the classification enhancement for the improving the result.

Malaya Kumar Nath (2012) has written a good review paper [6]. They have described the sufficient work related to Glaucoma detection. By reading this paper we can get the idea about the factors which is responsible for the Glaucoma, technique by which we can evaluate these parameters to find the glaucomatous eye. On the basis this review report that the normal disc lies between 0.3 to 0.5 and the Glaucomatous disc lie in above more than 05. But for some normal cases it may lie in range of 0.4 to 0.6 also. This disease is more harmful for the aging society. They have described the following work related to Glaucoma.

Gloster and parry (1974) evaluated the cupping part from the optic disc using the fundus retinal images. Visual fields also changes during the Glaucoma. The following parameters are evaluated by them diagnosis of Glaucoma.

- Cup to disc ratio
- Cup horizontal diameter to disc horizontal diameter

- Cup vertical diameter to the disc vertical diameter

Funk et al. Evaluated the relation between the neuroretinal rim area and age in normal subjects by using RONAHA (Rodenstock optic Nerve Head Analyzer). Linear regression is used to correlate neuroretinal rim area and the function of age. However they are not able to calculate the linear correlation between the neuroretinal rim and age. Result of the analysis is that there is no change between the rim area w.r.to ages but there is decrease of .2mm². Neuroretinal rim area is used for the detection of Glaucoma. Neuroretinal rim area can be calculated by the subtracting the cup from the disc area. Author calculated that NRA is increases with Age.

Corona et al. find the limitation of the evaluation of the factors that helps in detection of the Glaucoma. He has done the pro-processing for the optimizing the images by finding the 3-D surface from the 2-d stereo.

Pueyo et al. describe the neuroretinal rim and optic disc area as function with age. They use the Gabar filtering and computer aided detection (CAD) and colour fundus images. Author has tested the procedure over 200 eye image which is obtained from the ophthalmology Hospital. He detected the damaging of the retinal nerve fiber layer for the diagnosis of the Glaucoma. The author uses the Gabor filtering to the Grey scale of the retinal images for segmentation of the optic disc. Then he applies the morphological closing for the blood vessel elimination. To enhance the retinal nerve fiber layer he uses the Gabor filter with Gaussian filter. Optic disc size is measured by the histomorphometry, slit-lamp biomicroscopy and planimetry. Accurate measurement is done by the confocal scanning laser ophthalmoscopy. Larger size of the disc indicates that larger area of the neruretinal rim.

Wong et al. Finds the automatic measurement of the cup to disc ratio for the Glaucomatous eye analysis. They used the different technuqe of the segmentation for finding the optic cup and the optic disc form colour fundus images. These technique are colour histogram analysis, level set method etc. CDR is calculated by the different method. These obtained CDR is merged with the help of the adaptive neural network. The procedure is tested over the images which obtained from the Singapore Eye Research Institute.

Nayak et al. has use the following parameter for the diagnosis of the Glaucoma. First parameter is cup to disc ratio and this parameter increases due to the shifting of the optic nerve head towards the nasal. The second parameter is ratio of the distance optic disc centre and optic nerve head to the diameter of the optic disc. And the third parameter is area of the blood vessels in the inferior side of the nasal. These parameter is used with neural network for the classifying the normal and the Glaucomatous eye. The author used the green channel and Red channel image for the segmentation purpose. Firstly he eliminated the blood vessels for the fundus images with the help of the morphological operation because the blood vessels have the less effect on the Glaucoma. According to the author the green channel image have good intensity and clear boundary for cup. So the green channel image is used for obtaining the cup from the disc. For obtaining the centre of the optic nerve head they used the bottom hat transform. The brightest pixel from this transform will be the centre of the optic nerve head.

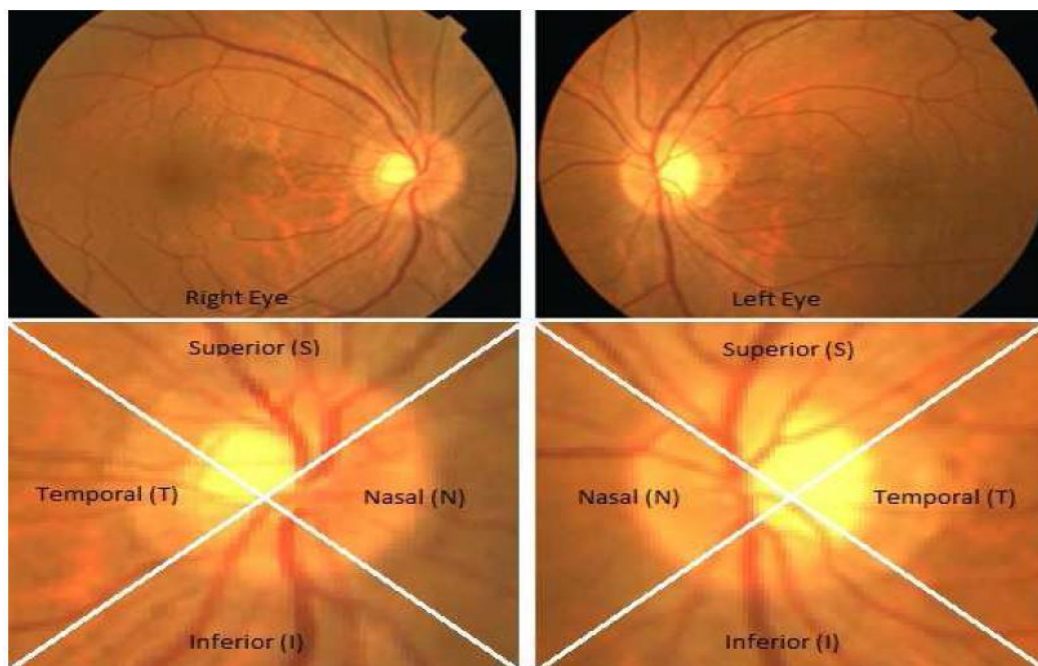


Fig.4 this figures describes the different region of the fundus image. These regions have the area of interest.

This method provides a classification rate of 90%, sensitivity 100% and the specificity 80%. Jimenez and all studied the structural pattern of the retina for the detection purpose of Glaucoma with the help off multifocal electroretinography. ERG is defined as the collection of the bioelectric signals due to retinal cell activity. Author finds the peak amplitude and maximum latencies in wavelet domain for the detection of the Glaucoma. In the proposed method, the structural patterns have extracted from the ERG data and this is given to the radial basis neural network for the classification pattern. The author concluded that analysis of the data provides good specification about the Glaucoma.

Bock et al. Have done the classification using the PCA and SVM. They have done the pre-processing step to optimize the image for the classification purpose. Classification is done between the Glaucoma and the non Glaucomatous image.

4 Conclusionand future work

A substantial amount of work has already done in the field of the detection and classification of Glaucoma. But none of the existing techniques are able to give accurate result. There are the several factors which get change due the Glaucoma disease. Several researchers have taken different factors for the detection of the Glaucoma and its classification. There are the wide area of change around the optic nerve fiber layer and visual field region. So it is covers the wide area of research field and a lots of research work has to be done by the researchers. As I have been already described that it is non curable and irreversible disease. So the early detection of the Glaucoma is very essential. This disease is second largest cause for the world blindness.

So this is very important for the researcher to discover the new technique for detection and classification of the Glaucoma. New technique should be able to give the information about the stages of the Glaucoma. So the doctor can start the treatment according to the stage of the disease.

So in future, the possible work can be research the new technique that is able in accurate detection and classification. To achieve this goal they can combine more than one factor. There is possibility to search new indicator for the Glaucoma identification. So in future, these are the possible work for Glaucoma identification and its classification.



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