CHAPTER 1
INTRODUCTION

Computer vision and image processing procedures play an essential part in the field of medical science and are particularly important to ophthalmology. Medical imaging permits researchers and doctors to comprehend potential life-sparing data utilizing less intrusive strategies. Applications that can interpret an image are being created, which thus can help a medical practitioner in distinguishing conceivable abnormalities. The speedy progress in medical imaging has driven the researchers in the direction of developing a mixture of image processing algorithms for detection, segmentation and classification of anatomical structures and pathologies.

The retinal fundus imaging now becomes a main component in contemporary eye treatment. Computerized medical imaging has provided valuable information to scientists and ophthalmologists with fewer invasive technologies. Digital fundus imaging in ophthalmology plays a significant role in the diagnosis of some pathology like hypertension, diabetes, arteriosclerosis, cardiovascular disease and stroke. Due to the rise in population strength, the diagnosis of retinal disease becomes a cumbersome process for the medical practitioner. The advancements known as Computer Aided Diagnosis (CAD) frameworks demonstrate that CAD can be useful to help the analytic exactness of doctors and lighten the workload burden. Evolving new diseases day by day become a challenging task for the researchers to discover new techniques to support the ophthalmologist in decision making. Diabetic Retinopathy and Glaucoma are the main noteworthy eye-related diseases which lead to permanent vision loss if earlier diagnosis and treatment fail.
1.1 ANATOMY OF THE HUMAN EYE

The human eye is the most complex organ in human body. The structure and main components of human eye given in the web portal http://maculacenter.com/eye-anatomy/ are shown in Figure 1.1. In most of the ways, human eye works like a digital camera where the light focussed by the cornea acts as the camera lens. Iris of eye functions as diaphragm of camera and controls the light reaching the back of the eye by auto adjustment of pupil. The lens located behind pupil focuses automatically on close to objects similar to autofocus camera lens. The light reaches the back part of the eye called retina which is light sensitive. This retina converts optical images into electronic signals, and the optic nerve transmits these signals to the visual cortex. The optic nerve connects eye to the brain and brings retinal blood supply. The Macula which is dark red is responsible for fine central colour vision focus for reading and writing. The centre of Macula is the fovea that provides sharp points of individual vision. The Optic Disc (OD) is characterized with bright yellowish colour from which the Retinal Blood Vessels (RBV) and optic nerve emerge. The detection of OD and RBV is of primary significance in clinical assessment of patients like pregnant woman, and diabetes patients for automated disease diagnosis.

![Figure 1.1 Anatomical structure of the human eye](image-url)
1.2 FUNDUS IMAGING

Fundus imaging is characterised as the procedure whereby a 2-D representation of the 3-D retinal semi-transparent tissues anticipated onto the imaging plane is acquired utilizing reflected light. In this manner, any procedure which brings out a 2-D picture, where the picture intensities speak to the power of a reflected amount of light, is fundus imaging. Fundus cameras are utilized by optometrists, ophthalmologists and prepared medicinal experts to diagnose disease progression, conclusion of abnormality or in screening programs. Organized ophthalmoscope is one that produces an upright or un-reversed picture of around fifteen times amplification. Backhanded ophthalmoscope creates an altered direct picture of two to five times amplification.

Eye fundus photography is viewed as the favoured indicative methodology since it is dependable, non-obtrusive and simple to utilize. As opposed to customary ophthalmoscope, it permits to record symptomatic information and empower the master conference a short time later. Hutchinson et al. (2000) have expressed that the eye fundus photography brings about a superior affectability rate, that is, a superior identification rate of irregular eye fundus. Because of the fast improvement of computerized imaging, the eye fundus camera likewise gives simple to document pictures in convenient configuration that empowers programmed diagnosis of diabetic retinopathy utilizing image processing techniques. An eye fundus camera is shown in Figure 1.2.

The images obtained from the fundus camera provide a view on the eye interior surface called fundus. The digital fundus image view of right and left eye is shown in Figure 1.3. A healthy fundus image clearly gives an idea about the anatomical structures like Optic Disc, Macula and Blood Vessels as shown in Figure 1.4 (a). However, an abnormal image has the sign and
symptoms of pathological features like microaneurysms, exudate, and hemorrhages as shown in Figure 1.4 (b).

Figure 1.2 Fundus camera

Figure 1.3 Digital fundus image views (a) Right Eye. (b) Left Eye

Figure 1.4 Type of fundus images – Diabetic Retinopathy (a) Healthy fundus image, (b) Abnormal fundus image
1.3 DIABETIC RETINOPATHY

Diabetic Mellitus (DM) commonly referred to as diabetes is a metabolic disease caused due to the high blood sugar level prolonged over a period of time. Diabetes in human retina is referred to as Diabetic Retinopathy (DR), one of the most general retinal diseases that take place when there is an abnormality in the retinal blood vessels. The rise in glucose level of retina injures the tiny blood vessels (capillaries), commences to leak fluid and fats, causing swelling (edema) and has the possibility of vessel close off (ischemia). This has been identified as the signs of Non-Proliferative Diabetic Retinopathy (NPDR). Diabetic Retinopathy (DR) is a sight-threatening risk inflicting in diabetic patients. Early diagnosis and treatment prevent visual loss and blindness. Retinal images obtained by the fundus camera are used to diagnose DR. Automated methods of DR screening help to save time, cost and vision of patients, compared to the manual methods of diagnosis.

1.3.1 Signs and Symptoms of Diabetic Retinopathy

The patient affected by diabetes does not have the earlier signs and symptoms which will affect the blood vessel of retina. Hence patients remain undiagnosed without recognising the severity of retinal blood vessel damage that leads to permanent vision loss. In the earlier stages of DR, there may be mild blurred vision which may be temporary and vanish after a few hours. Prolongation of blood vessel damage may suddenly lead to bleeding without any signs and cause sight loss. The following are the symptoms of DR observed commonly in retina.

- Spots or dark strings (floaters)
- Blurred vision
- Fluctuating vision
- Impaired colour vision
- Dark and empty areas in vision
• Vision loss

The physical signs and symptoms developed due to the blood vessel damage are Microaneurysms, Hemorrhages and Exudate. The examination of fundus images is very much essential to spot the abnormal physical signs. The following section describes the pathological features for better understanding and knowledge.

1.3.1.1 Microaneurysms

The first detectable abnormalities are microaneurysms (MA) which are local distensions of the retinal capillary. MA is tiny, red spots or miniscule hemorrhages, appearing alone or in clusters. These are 10 to 100 microns and less than 125µm in diameter and are circular in shape. Therefore, early detection of diabetes can be performed by monitoring the MA. The microaneurysm present in the fundus image is illustrated in Figure 1.5 (Courtesy: http://medweb4.bham.ac.uk/MBChB_CAL/Bain_Retinopathy/tour/diabetes/microaneurysms.html).

![Microaneurysm](image)

Figure 1.5 Fundus image showing microaneurysm

1.3.1.2 Hemorrhages

The second noticeable abnormalities are hemorrhages which are the extended stage of microaneurysms where the tiny red dots further develop as
circular dark dots clearly visible named as hemorrhages. It is simply referred to as abnormal flow of blood from ruptured blood vessels. The hemorrhage marked in the fundus image is illustrated in Figure 1.6 (Courtesy: http://www.suggest-keywords.com/cmV0aW5hbCAgaHlwZXJ0ZW5zaW9u/).

![Fundus Image](http://www.suggest-keywords.com/cmV0aW5hbCAgaHlwZXJ0ZW5zaW9u/)

**Figure 1.6 Fundus image showing hemorrhage, hard exudate and soft exudate**

### 1.3.1.3 Hard and Soft Exudate

In addition to leaking blood, the vessels will also leak lipids and fatty and protein-based particles from the bloodstream into the retina causing small bright dots called exudate to appear. Such a phenomenon prevents light from reaching the retina thereby leading to visual impairment. Intra-retinal fatty (hard) exudates are vital and visible signs of DR and also a marker for the presence of coexistent retinal edema. If accumulated in the central part of the retina (macular area), edema and exudate are a major cause of visual loss in the non-proliferative forms of DR. Exudate are associated with patches of vascular damage with leakage and typically manifested as spatially random yellow-white patches of varying sizes and shapes. Next, small parts of the retina become ischemic deprived of blood. These ischemic areas are visible on the retina as fluffy whitish blobs called cotton wool spots (soft exudate). The hard and soft exudate
in fundus image is shown in Figure 1.6 (Courtesy: http://www.suggest-keywords.com/cmV0aW5hbCAgaHlwZXJ0ZW5zaW9u/).

1.3.1.4 Neovascularization

The blocked blood vessel from ischemia leads to the growth of new abnormal blood vessels on the retina called neovascularization. This newly grown blood vessel may damage retina by causing wrinkling or retinal detachment. The study reveals that neovascularization may lead to the cause of glaucoma retinal disease which damages the optic nerve that carries signal from eye to brain. The image showing growth of new blood vessel and retinal detachment is shown in Figure 1.7 (a) to (b) (Courtesy: http://medweb4.bham.ac.uk/MBChB_CAL/Bain_Retinopathy/tour/index.html).

![Neovascularization](image1.png) ![Retinal detachment](image2.png)

Figure 1.7 Retinal disorders (a) Neovascularization in retinal image (b) Retinal detachment in retinal image

1.3.2 Types and Grading of Diabetic Retinopathy

Basically, diabetes is classified into two main types. Type-1 diabetes and Type-2 diabetes. Type-1 diabetes is one where the human body immune system attacks cells in its own pancreas producing beta cells and destroy them. Hence the insulin production gets stopped and the sugar content rises in the blood and human body starves from lack of glucose. Type-2 diabetes is more
common in the age of above 35 years and is able to produce some of their own insulin. However, the insulin does not have the efficiency to resist the glucose from entering. Sensing rise in blood glucose level, the pancreas produces grater amount of insulin to manage blood glucose.

The screening of fundus images is necessary to categorise the retinal disease based on the signs and symptoms present for the purpose of early treatment diagnosis process. The DR can be classified into

1. Non-Proliferative Diabetic Retinopathy (NPDR)
2. Proliferative Diabetic Retinopathy (PDR)

The early stage of DR is the NPDR and the advanced stage of DR is PDR. Further, early DR is graded as Mild NPDR, Moderate NPDR and Severe NPDR. However, the PDR is graded as early PDR and risky PDR. (Courtesy:http://www.mayoclinic.org/diseases-conditions/diabetic-retinopathy//basics/courses/). A non-proliferative retinal image is illustrated in Figure 1.8

![Figure 1.8 Stages of non-proliferative DR images](image)

(a) Mild  (b) Moderate  (c) Severe

**1.3.2.1 Mild NPDR**

The initial development of abnormal feature microaneurysms in the retinal image is observed as edema in the blood vessel walls. This feature appears as tiny red coloured dot formation.
1.3.2.2 Moderate NPDR

In the next stage to microaneurysm, the hemorrhages and soft exudate may show their signs either independently or as group of clusters. There will not be any warning signs of vision loss, and therefore continuous monitoring of patients’ record is essential to avoid vision loss.

1.3.2.3 Severe NPDR

This is the most severe stage of NPDR in which the cotton wool spots, venous beading and severe Intra-Retinal Micro vascular Abnormalities (IRMA) are present in the retinal images. The image is diagnosed as severe NPDR if it has microaneurysms and hemorrhages in all the four quadrants or venous beading greater than or equal to two quadrant or IRMA greater than or equal to one quadrant. Most of the patients that fall in this category may progress to PDR if not properly treated by the ophthalmologist.

1.3.2.4 PDR

The proliferative retinopathy image exposed in Figure 1.9 shows the injured blood vessels shut off, causing new vessel growth in the retina which can leak into clear; jelly-like substance that fills up the centre part of the eye referred to as early PDR. However, the wound tissue enthused due to the new abnormal blood vessel may cause the retina to separate from the back of the eye which is referred to as risky PDR.

Figure 1.9 Proliferative DR fundus image
1.4  GLAUCOMA

Glaucoma is a disease of the optic nerve caused by the increase in the intraocular pressure of the eye. Glaucoma mainly affects the optic disc by increasing the cup size. It can lead to the blindness if it is not detected and treated in proper time. The detection of glaucoma through Optical Coherence Tomography (OCT) and Heidelberg Retinal Tomography (HRT) is very expensive. Digital fundus images using image processing techniques such as pre-processing, morphological operations and thresholding, are widely used for the automatic detection of optic disc, blood vessels and computation of the features. Glaucoma is a progressive optic neuropathy with characteristic structural changes in the optic nerve head reflected in the visual field. Worldwide, it is the second leading cause of blindness. It affects one in two hundred people aged fifty years and younger, and one in ten over the age of eighty years. In most cases, it is detected only after loss in vision. Vision loss is caused by damage to the optic nerve, which carries image information from the light receptors to the brain. There is no cure for glaucoma yet. Hence early detection and prevention is the only way to avoid total loss of vision.

1.4.1  Types of Glaucoma

There are two main types of glaucoma. They are primary open angle glaucoma, and angle closure glaucoma. These occur due to increasing intraocular pressure (IOP). The retinal disease glaucoma cannot be completely cured, but the growth can be controlled if early diagnosis and proper treatment is carried out with clinical practice.

1.4.1.1  Primary Open Angle Glaucoma

This is the most common type of glaucoma shown in Figure 1.10. It happens when the eye’s drainage canals become clogged over time. The inner eye pressure (IOP) rises because the correct amount of fluid cannot drain out of
the eye. With open angle glaucoma, the entrances to the drainage canals are clear and work properly. The clogging problem occurs further inside the drainage canals, similar to a clogged pipe below the drain in a sink. If open angle glaucoma is not diagnosed and treated, it can cause a gradual loss of vision. This type of glaucoma develops slowly and sometimes without noticeable sight loss for many years. It usually responds well to medication, especially if identified early and treated.

![Fundus image showing open angle glaucoma](image)

**Figure 1.10 Fundus image showing open angle glaucoma**

### 1.4.1.2 Angle Closure Glaucoma

This type of glaucoma is also known as acute glaucoma or narrow angle glaucoma as shown in Figure 1.11. It is rare and is different from open angle glaucoma. This happens when the drainage canals get blocked or covered over, like a sink with something covering the drain. In this angle closure glaucoma, the iris is not as wide and open as it should be. The outer edge of the iris bunches up over the drainage canals, when the pupil enlarges too much or too quickly. This can happen when entering a dark room. Treatment of angle closure glaucoma usually involves surgery to remove a small portion of the outer edge of the iris. This helps to unblock the drainage canals so that the extra fluid can drain.
1.4.2 Impact of Glaucoma on Diabetic Retinal Images

In a fewer cases of diabetic retinopathy, the retinal blood vessels are damaged because of the increase in blood sugar level thereby close off the vessels in the retina. The retina manufactures new abnormal blood vessel and if this occurs in iris part then it is referred to as Neovascular Glaucoma. The eye pressure rises due to the close-off of the blood vessels. People with diabetes are twice as likely to develop glaucoma as are non-diabetics. (Courtesy: http://www.glaucoma.org/glaucoma/diabetes-and-your-eyesight.php). For this reason study has been made to analyze the impact of glaucoma disease over diabetic retinopathy, and the results have been validated with the eye specialist.

1.5 DISEASE DIAGNOSIS

Diabetic retinopathy, the most common complication of diabetes which causes blindness in the adult can be diagnosed based on clinical examination and eye fundus photography. The second prime retinal disease glaucoma diagnosis includes the measurement of intraocular pressure, change in size of the optic disc and cup, shape of the eye and examination of cup to disc ratio and vascular damage. Normally, the eye fundus photography is preferred for diagnosing the retinal diseases, and for the case where the fundus image is
unavailable, the clinical eye examination is used. It is significant to note that it is not probable to diagnose retinal disease by means of the laboratory test. In the screening of DR and glaucoma, the medical practitioners make use of the fundus image or direct ophthalmoscope to examine the retina stages.

1.6 SCREENING

Screening process in DR includes imaging of the fundus and distinguishing proof of the variations from the norm by specialists. Appropriate screening for DR at the early stage will lessen the danger of visual impairment. In the screening procedure, fundus picture is caught utilizing a unique computerized gadget called Fundus Camera. Excellent fundus photos can identify most clinically significant DR. The fundus pictures are classified as normal or abnormal in view of the nearness of physical signs in the pictures. In the irregular cases, in view of the seriousness, the suggestions need to be given for further treatment. In the event that the investigation of the images is done by specialists, it is named as manual screening, then again in the event that it is done utilizing an image handling algorithm, it is named as auto-screening process.

Early identification of retinopathy in view of a legitimate screening technique is profoundly basic in preventing visual hindrance. Identification and reviewing of DR from retinal images is tedious and redundant. It is therefore of awesome enthusiasm to build up a programmed DR screening framework with ability of separating between individuals with no retinal anomalies and some sort of anomalies. Since there are no salient signs in the early phases of diabetic retinopathy, and the quantity of signs and symptoms dominantly increment with time, a knowledge screening over huge populaces is required. Disciplined screening for DR ought to make an essential commitment to the safeguarding of vision for individuals with diabetes. A programmed approach including fundus
image investigation by computer could give a prompt grouping of retinopathy without the requirement of specialists.

On account of glaucoma, screening can recognize indications of expanded Intra-Ocular Pressure (IOP) and the early phases of Primary Open-Angle Glaucoma (POAG). The damage to optic nerve strands can make blind sides. These blind sides normally go undetected until the optic nerve is fundamentally harmed. Since glaucoma advances with almost no notice signs or side effects, and vision misfortune from glaucoma is irreversible, it is critical that individuals at high hazard for the sickness get a yearly screening.

Because of lacking number of ophthalmologists and sharp increment in diabetics, the analysis of DR and glaucoma is getting to be plainly troublesome and tedious. It prompts the requirement for improvement of programmed screening of fundus images. The auto-screening process can be utilized for screening substantial number of images precisely by the medical graders with partial skills.

1.7 MOTIVATION OF RESEARCH WORK

The medical practitioners are struggling in detecting the retinal diseases for diagnosis. DR and Glaucoma are the two major significant eye diseases that lead to vision loss if proper analysis and action fail. The World Health Organization (WHO) predicted that the number of persons with diabetes will increase to 366 million in 2030 worldwide (WHO Report 2010). In 2014, WHO surveyed that even in the United States 29.1 million persons were affected by diabetes. This may increase to about 34 million by the year 2016. Diabetic Retinopathy (DR) and Glaucoma are the major irreversible disorders related with human retina. DR is caused by diabetes of the patients, and the diabetic patients may or may not have the Glaucoma disorder. Screening both retinal disorders is important to prevent earlier vision loss.
The number of ophthalmologists required for evaluation by direct examination becomes a limiting factor due to ageing, population growth, physical inactivity and obesity which contribute to increase the risk of vision loss. However, in large-scale screening scenario, these manual assessments are not precise, mostly in developing countries due to the insufficiency of trained experts and scarce modern imaging equipment. Hence an automatic recognition system which habitually identifies the characteristics of these pathological disorders may be of great advantage for the disease identification in medical imaging system. In this research work, development of digital image processing techniques towards segmentation of Optic Disc (OD), Retinal Blood Vessels (RBV) and classification of retinal disease, Diabetic Retinopathy (DR), Glaucoma and study on impact of glaucoma in DR images is focussed.

1.8 OBJECTIVE OF RESEARCH WORK

The main objective of the research work is to build up efficient image processing techniques using computational intelligence.

1. To segment anatomical and pathological retinal structures using various image processing techniques for the detection of Diabetic Retinopathy (DR) and Glaucoma.

2. To analyze the fundus images using computational intelligence methods, to sequentially classify DR images into normal and abnormal images and to categorize the severity of the DR retinal disease based on the abnormalities level present in the ocular images.

3. To study the fundus image features based on Cup to Disc Ratio (CDR), blood vessels in ISNT and Neuro Retinal Rim (NRR) region for glaucoma classification and grading.

4. To facilitate and to improve the performance measures by combining different features, classification, post-processing and to compare various proposed techniques with the existing methods.
1.9 APPLICATIONS

Evaluating the eye fundus images is tedious and consumes much time. It requires consideration of an ophthalmologist and makes the determination inclined to errors. Automatic image examination and analysis on fundus image give a potential solution for the issue. Via mechanizing the reviewing procedure, more patients could be screened and referred for further examinations, in this manner empowering the ophthalmologists to have more opportunity for patients who require their consideration. A computerized framework assists nearby wellbeing laborers with detecting glaucoma and diabetic retinopathy cases without the requirement of nearby ophthalmology specialists. One can perform early recognition of DR and glaucoma cases in rural areas utilizing automatic fundus image investigation via preparing and training the workers and organizing wellbeing camps without the requirement of neighborhood specialists or even web network.

1.10 ORGANIZATION OF THESIS

Chapter 1: An introduction to the components of visual observation, glaucoma and diabetic retinopathy complications with their suggestions to vision is described in this chapter. Further inadequacies of the current analysis framework and the advantages of automated fundus image investigation are discussed.

Chapter 2: A brief writing on literature survey with the existing methods of optic disc, optic cup, blood vessel segmentation, exudate, microaneurysm and hemorrhages for the detection of DR and glaucoma is presented in this chapter.

Chapter 3: The segmentation of the anatomical structures, optic disc and blood vessels using modified region growing algorithm, orientation analysis gradient vector field and morphological features is presented. Also, the
pathological structures like microaneurysm, hemorrhages and exudate have been detected using morphological operations, and the performance measures evaluated and compared with few other techniques are discussed.

**Chapter 4:** An approach for the diagnosis of the fundus images using features followed by the neural network classifier for classification of images is explained. Also, the classification considering only anatomical structures and with anatomical and pathological structures has been studied, and the results are provided. Finally, the severity grading of DR using features from exudate and hemorrhages followed by SVM classifier is presented.

**Chapter 5:** The importance of optic disc and optic cup segmentation using the green and red channels with morphological approach along with CDR, ISNT features followed by neural network classifier is explained. Also, the wavelet decomposition and feature extraction method are discussed with the graphical user interface model developed.

**Chapter 6:** The neuro retinal rim from OD and OC segmentation and features such as CDR, GLCM and ELBP followed by SVM classifier are presented for the grading of glaucoma. Also, the impact of glaucoma in DR images has been analysed and presented along with the validation of ophthalmologists.

**Chapter 7:** An overview of the entire work, performance measures, conclusion and future scope of investigations for improvement are explained in this chapter.

### 1.11 SUMMARY

This section gives a prologue to the components of visual observation, diabetic retinopathy and glaucoma with their suggestions to vision, related eye maladies with their side effects, the analytic techniques, and
modalities, inadequacies of the current framework and the advantages of computerized eye fundus image examination. It additionally manages the requirement for programmed finding and screening to distinguish early phases of the disease. The uses of the programmed recognition framework to analyze diabetic retinopathy and glaucoma are discussed.