A Novel Approach to Glaucoma Detection with Cup-to-Disc Function using MATLAB

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Abstract

This research focuses on the early detection of glaucoma using digital fundus images and MATLAB-based image processing techniques. The process begins by converting the original RGB eye images into grayscale to simplify the data and reduce computational complexity while retaining essential structural information. After grayscale conversion, contrast enhancement is applied to improve the visibility of key features such as the optic disc and cup. Enhancing contrast is critical as it highlights subtle differences in intensity, which may indicate early signs of glaucoma that are not easily noticeable in the original image. Once the image quality is improved, the optic disc is segmented, which is an essential step because the optic disc is a primary region of interest in glaucoma diagnosis. Following segmentation, thresholding is used to differentiate between the optic cup and the surrounding retinal regions. Thresholding is necessary to isolate specific intensity levels, making it easier to distinguish the optic cup from the optic disc and calculate the cup-to-disc ratio (CDR). This ratio is a vital clinical indicator of glaucoma, as a larger CDR often signifies potential damage to the optic nerve. The final stage of the Research involves calculating the CDR and using it as a basis to detect the presence of glaucoma. By automating these steps in MATLAB, the system provides a consistent, objective, and efficient method for glaucoma detection, which can be used by the ophthalmologists in early diagnosis and treatment planning.

Chapter 1

1 Introduction

Glaucoma is often termed as the silent snatcher of vision and affects a majority of the elderly population. The early detection of glaucoma and elevated inter ocular pressure is critically significant to arrest the progression of the irreversible disease. With the ocular degeneration of the retina and optic nerve, and other ailments such as high blood sugar levels, chronic blood pressure, thyroid imbalance and cataract, manual detection of glaucoma is often challenging leading to significant vision loss at the time of detection. Moreover, at low-income group countries, medical costs also act as a deterrent for the early detection of the disease-causing permanent vision loss. Hence, research on the development of automated tools has been of paramount importance which can detect glaucoma with low false negative and false positive rates. Several machine learning and deep learning methods have been explored along with image enhancement techniques with an aim to attain high accuracy of classification based on image features such as the cup to disc ratio (CDR). In this paper, an image enhancement and feature extraction technique is developed which is subsequently used to train a deep neural network. Gray Level Co-occurrence matrix based features along with the cup to disc ratio have been used to train a Deep Bayes Net with regularization for automated detection of glaucoma. The impact of feature combinations has also been evaluated using the linear discriminant analysis (LDA). The performance of the proposed system has been evaluated in terms of the classification accuracy of the system. It has been shown that the proposed system attains a classification accuracy of 98% with moderate number of iterations, which makes the performance comparable to existing benchmark machine learning techniques in the domain. The relatively low computational time and training epochs makes the technique suitable for hardware constrained devices which can cater to a wider population worldwide.

1.1 Glaucoma at glance

One of the deadliest diseases which happen to affect the eye-sight of the elderly, globally happens to be glaucoma. Along with diabetic retinopathy, glaucoma causes over 50% of permanent visual impairment especially under persons over the age of 55[1].

The extent of severity and impact however depends on the race and age, along with co-morbidities such as history of cancer, thyroid malfunction, blood pressure etc. A comparative analysis of the prevalence of glaucoma for different ethnicities and age groups is depicted in figure1. It has been found that glaucoma accounts for around 3 million cases of complete blindness and approximately 4 million cases resulting in visual impairment worldwide [2]. It is apprehended that the number of people affected by any sub-type of glaucoma will exceed a staggering 110 million by 2040. Although glaucoma can be found to affect people irrespective of their age, however higher chances of occurrence (in between 1%-4%) is found among patients over the age of 40 [4] . The fundamental reason for the onset of glaucoma is the elevated level of intraocular pressure (IOP). Increased levels of IOP adversely affect the optic nerve causing irreversible damage, resulting in loss or impairment in vision depending on the magnitude of damage [5].

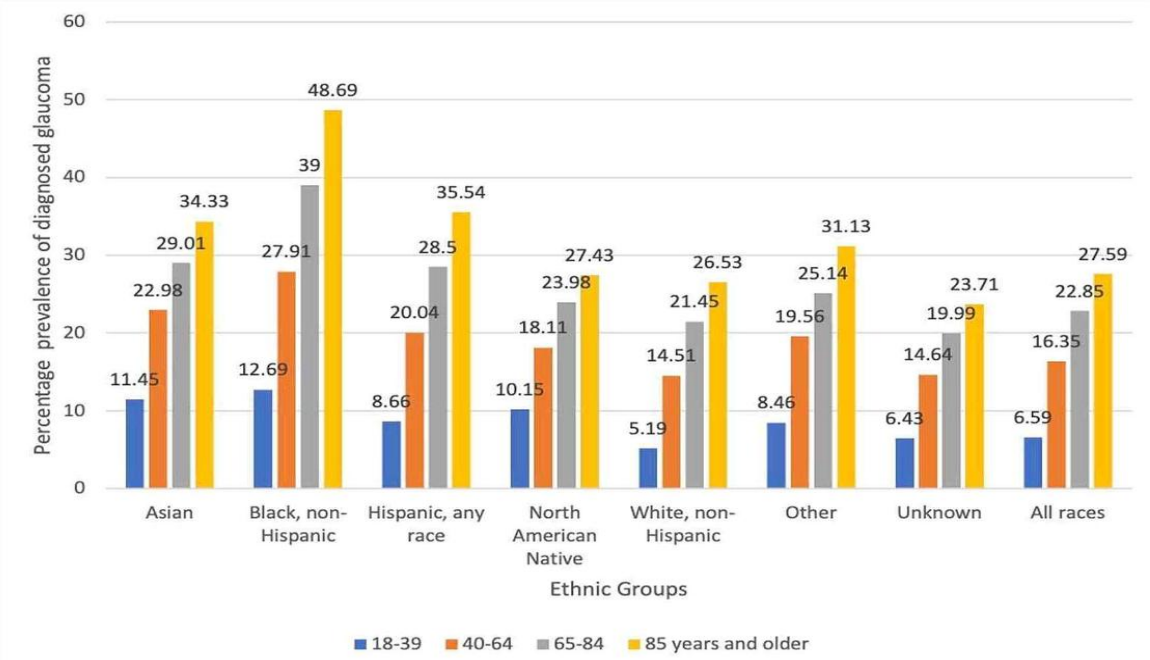


Figure1. Age and ethnicity wise glaucoma statistics

The fundus images obtained from fundus imaging need to be processed and analysed to extract critical features for the decision on presence or absence of glaucoma or pre-glaucoma like symptoms [12]-[13]. Due to the occurrence of noise and disturbance effects while capturing, retrieving, processing and storing the images, the final classification may be prone to errors [14]. This necessitates case sensitive noise removal and image restoration techniques which can enhance the quality of the images under interest so as to facilitate feature extraction and pattern recognition [15]. The retina is a layered tissue which is responsible for conversion of light signal into electrical signals for the brain to garner a sense of sight [17]. A typical retinal image is depicted in figure 2 which consists of blood vessels, optic disc (OD), Optic Cup (OC) and the macular region.

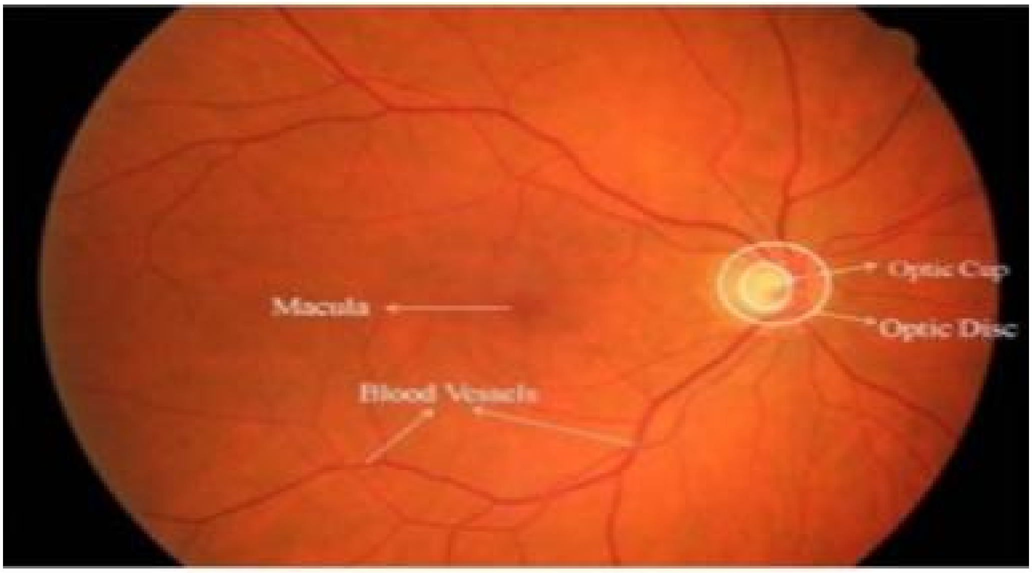


Figure 2: A typical fundus images for detection of glaucoma

Thus the retina is responsible for the creation of the optic images in the eye which are perceived by the brain as equivalent electrical signals giving a view of the outside world. In general, several physical ailments can result in the damage to the optic nerve and retinal function, among which hypertension, diabetes and other cardiovascular diseases are prominent [18]-[19]. A significant part of the above causes is diabetic retinopathy which is caused by excess blood sugar levels in the blood streams causing irreversible damage to the heart, lungs, kidneys and eyes. Typically, patients suffering from type-2 diabetes often suffer from diabetic retinopathy and this causes serious damage to the peripheral vision in humans [20]. In developed countries, glaucoma is also termed as the silent snatcher of eyesight, which can only be arrested but not reversed making its early and accurate detection extremely crucial [21]. With sedentary lifestyles, poor eating habits, depleting nutritional values in food intake, these diseases are often interconnected and are also progressing fast worldwide [22].

1.2 Anatomy of human eye

Eyes are an extension of the central nervous system that share many similarities with the brain in both anatomical and physiological properties. It consists of three-layered compartments, three fluids, and three coats or layers. The three layers are the fibrous outer coat, the vascular middle layer, and the inner nervous layer. The three compartments of the eye consist of the anterior chamber, posterior chamber, and vitreous chamber. The three intraocular fluids are aqueous humor, vitreous humor, and blood.

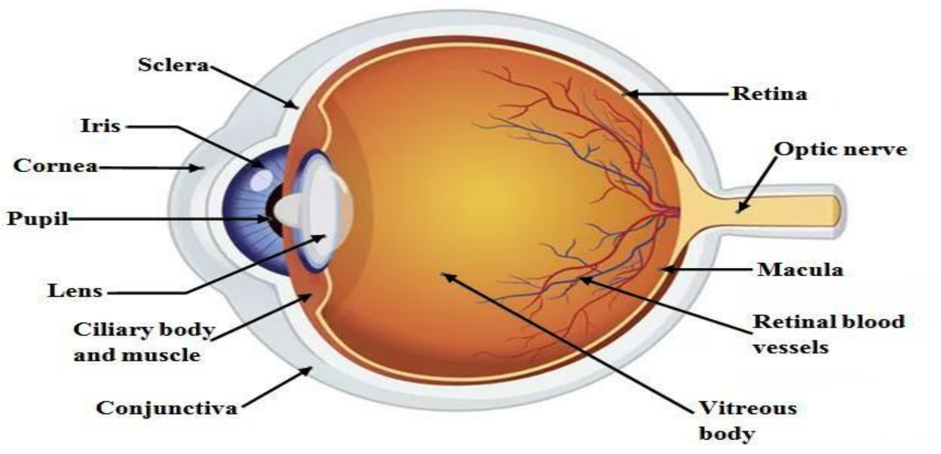


Figure 3 Anatomy of Human Eye

shape is maintained by a fluid-like substance called vitreous humor. The retina is the inner coat of the eye that allows the ray of light to enter the eyeball and form an image. The sclera is the outermost coat that maintains the strength and structure of the eyeball. Two-thirds of the optical power of the eye is attributed to the cornea, the anterior portion of the external coat of the eyeball.

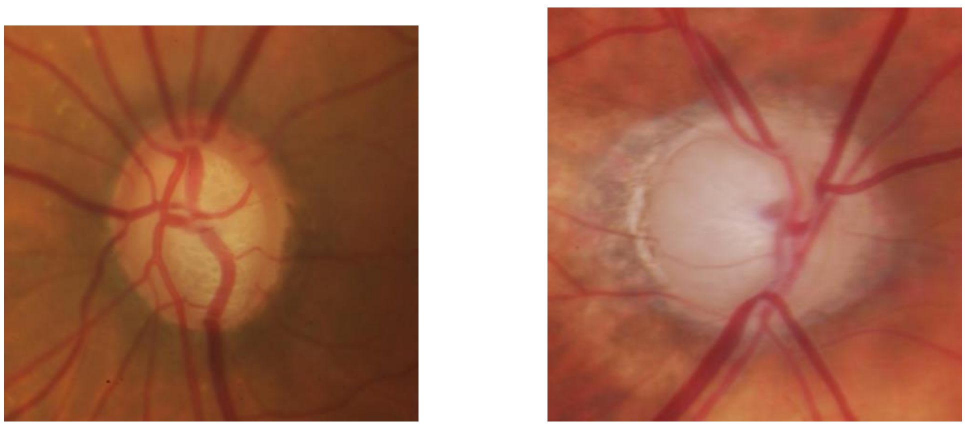


Figure 4 Retinal Fundus Image (a) Normal (b) Early Glaucoma (c) Moderate Glaucoma and (d) Severe Glaucoma

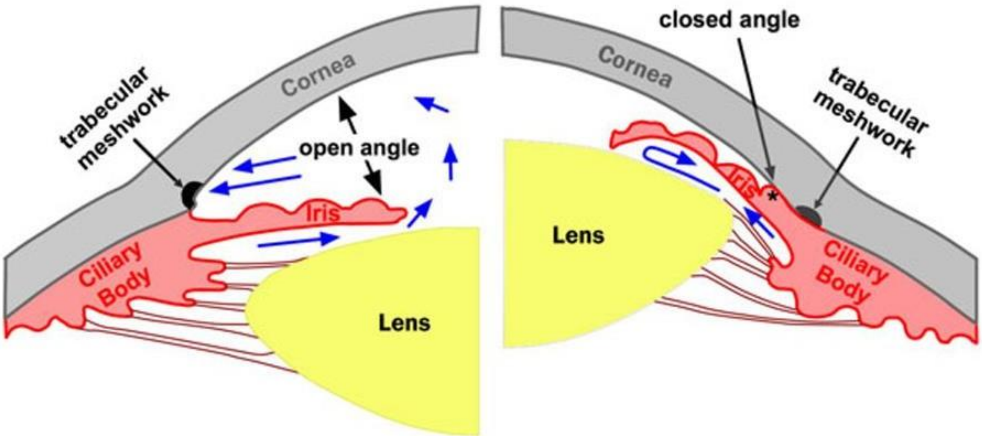


Figure 5 Open-Angle and Closed-Angle Glaucoma

1.3 RGB to Gray scale: Typically, acquired fundus images are contain three color channels which are Red, Green and Blue (RGB channels). Analyzing high resolution RGB images requires much higher compute power as compared to analyzing images with a single intensity variable as in the case of gray scale images

1.4 Noise removal

Noise removal is a critical process in digital image processing, aiming to improve the quality of an image by eliminating random variations, or "noise," that may degrade its visual appeal and analytical utility. Noise can occur during the image acquisition process, transmission, or due to sensor imperfections.

Chapter 2

LITERARURE SURVEY

[1] Nirmal Kaur, R.K. Bathla (2022) This study paper provides a variety of strategies for early detection of glaucoma affecting eye vision The CDR, an important glaucoma parameter of fundus images publically available from messidor and optic data bases were evaluated using three different methods namely morphological operations based on multithresholding techniques and region growing segmentation techniques.

[2] Jefferson Alves Sousa *et al.* (2021) developed a method to detect Age-related Macular Degeneration (AMD). This study presents a method for segmenting the Inner Limiting Membrane (ILM), bruch's membrane, and retinal pigment epithelium from Optical Coherence Tomography (OCT) images of normal and AMD patients who have intermediate AMD. For segmentation, U- Net and DexiNed deep neural networks are employed.

[3] Imtiaz *et al.* (2021) used Region Based Convolutional Neural Networks (RCNN) to partition the OD and OC. Feature extraction begins with the VGG16 algorithm. Recovery of missing features and subsequent split of the signal into the disc network and the cup network are performed by sending information via two divergent, parallel branches. In order to figure out where the OC should be placed, the system employs a disc attention module to parse the outcomes of the disc network and the cup network.

[4] Hasan *et al.* (2021) present an article on end-to-end networks designed for segmentation and localization of OD and Fovea by means of Dissecting and Reconstructing the convolutional neural network (DRNet) using MATLAB . The method used is based on circular area searching. However, to estimate the OD radius, the method requires information about the camera's range of view.

[5] Riaz Ali *et al.* (2020) presented a new approach using a fuzzy learning system for OD and OC segmentation for glaucoma screening. In this, extracting a region of interest from RGB images, performing data augmentation, extracting the red and green channels, and they are into separated two fuzzy learning neural networks for segmenting OD and OC, respectively, and then calculating CDR is computed.

[6] Zhang & Lim (2020) invented a hybrid strategy to identify the contours of OD and OC, which is also adaptively regularized and combines kernel-based Fuzzy C-Means (FCM) with the level set method to differentiate between the two. Al-Bander *et al.* (2018) invented a method for object classification utilizing super pixel classification, which classifies OD and OC. Super pixel classification uses histogram features and statistical data to find the disc boundary and it is where OD segmentation starts.

[7] Kausu *et al.* (2018) segregated optical disc by minimizing the objective function for grouping pixels. Otsu segmentation is used in thresholding to segment the OC. Soltani *et al.* (2018) utilized a Randomized Hough transform in combination with a Canny edge detection technique to obtain optical and optical contours in their research. To diagnose glaucoma, Chai *et al.* (2018) used a Fully Convolution Network (FCN) and collected the patient data and the contours of anatomical structure from case reports, and they were able to produce an image of the fundus.

[8] Julian *et al.* (2018) in their research used convolution neural networks to distinguish OC and OD images. The filters provide data that are then sent to a SoftMax logistic classifier, which is a classifier that uses logistic regression. Graph cut and convex hull procedures are used on the output of the classifier, which is then segregated. To segment OD and OC images, Perdoma *et al.* (2018) built a deep neural network with 15 layers.

[9] Sevastopolsky *et al.* (2017) present a modified U-Net architecture is to help with the segmentation of OD and OC. U-Net models possess Convolutional Neural Network (CNN) and they are the most vital part of a U-Net model. The latter of the two routes in this configuration grows while the former shrinks. The contracting route is implemented using the architecture of CNN with resolution layers that work well. The expansion layer resolution is very low. The contracting path's image data is merged with the growing path's data. Thus U-Net can identify patterns at a variety of scales.

[10] Fu *et al.* (2018) proposed M-Net as a method for carrying out segmentation of OD and OC. The design of M-Net uses a multiscale input layer. To get a multi-level receptive field, an image pyramid is first created by down- sampling images, which are then fed into the U-Net.

Chapter 3

3.1 Problem Definition

Glaucoma is a complex eye condition characterized by elevated intraocular pressure (IOP) that may progress to vision loss over time. This eye condition is categorized into primary or secondary types and further into open-angle or closed-angle variants. Adult glaucoma includes primary open-angle glaucoma (POAG) and angle-closure glaucoma, as well as secondary open and angle-closure glaucoma, with a specific focus on the most prevalent type, POAG.

Although the available treatments cannot cure existing optic nerve damage or reverse visual field loss, they can help control the disease progression through medication, laser treatment, or incisional glaucoma surgeries to help prevent further vision loss. These treatments aim to lower IOP and mitigate the impact of this vision-threatening condition through an interprofessional healthcare team for optimal treatment outcomes. This activity reviews various forms of glaucoma, including congenital, infantile, developmental, and juvenile variants, emphasizing cases primarily affecting individuals aged 40 and older. This activity also highlights the collaborative approach involving an inter professional healthcare team for glaucoma management due to its impact on vision. Early detection and regular monitoring are crucial for effectively managing glaucoma—the second leading cause of permanent blindness among older adults in the world.so it with the help of technology we can detect the glaucoma in early stage SO that necessary action can be taken with in time.

3.2 Objectives

1) Convert the RGB image to Gray scale image.
2) Convert Gray Scale Image to Binary image
3) Analysis and noise removal of fundus images from standard datasets.
4) Detect the glaucoma by run the glaucoma detection code with the help of CDR value using Matlab.

Chapter-4

Experimental Setup

4.1 Introduction

Simulation can be defined to show the eventual real behaviour of the selected system model. It is used for performance optimization on the basis of creating a model of the system in order to gain insight into their functioning. We can predict the estimation and assumption of the real system by using simulation results. Simulator, which is created by MathWorks, is one of the most dynamic and resourceful applications. It is basically a simulation platform that incorporates MATLAB and a model design system. It features a fantastic environment for programming, simulation, and modelling. Multi-domain dynamical systems can be analysed with this software by a variety of professions. Its principal interface consists of a graphical block diagramming tool and a collection of block libraries that may be customized. Moreover, it has amazing features such as product style control, traceability criteria, and application coverage analysis, among others. You will learn more about it in this article. Let's get this party started.

4.2 Simulator

In this thesis, MATLAB add-on product with a user-friendly, graphically appealing interface used for simulation programming and modelling. This tool allows any user to quickly and simply create virtual prototypes for exploring diversified design concepts at any degree of detail with minimum effort. You do not need any previous expertise to use this platform. Simply utilise a vast collection of preconfigured blocks to build graphical models of systems using drag-and-drop mouse operations to get started. It may represent nonlinear and linear systems in continuous-time, sampled time, or a combination of the two.

4.2 MATLAB Features

4.2.1 Introduction to MATLAB Simulator

In recent years, MATLAB has emerged as a powerful tool for image processing and enhancement due to its comprehensive set of functionalities and user-friendly environment. This section introduces the MATLAB simulator developed for the purpose of image enhancement, highlighting its key features and capabilities.

4.4 Methodology

The present work is carried out through a number of stages starting from problem selection to literature review about the state of art technology specific to Image Enhancement, and its application. As well as performing the simulation in MATLAB 2024. Most of the time is spent in identifying and selecting the problem and literature review. Selection of simulation tool and understanding the working of it also took a lot of time. The work in MATLAB has to stream through some steps. The work has executed step by step in MATLAB in MATLAB, These techniques are essential for tasks ranging from improving visual appearance to preparing images for further analysis or computer vision tasks, making MATLAB a powerful tool for image processing and analysis. In this thesis various methods of segmentation techniques used to diagnose retinal glaucoma based on the Cup to Disk Ratio (CDR) assessment of the pre-processed image. This paper discusses the assorted methods of segmentation techniques which are used to analyse retinal glaucoma by Cup to Disk Ratio (CDR) assessment of the pre-processed image. The diagnosis of glaucoma using the features obtained from the image on the basis of the study of the adaptive thresholding technique. A neural signal that's processed further within the cortical area of the brain.

5. Results

A human ophthalmologist separates a fundus image into three separate classes: optic cup, optic disc, and background. The neural network presented in the previous section was designed to recognize the optic disc, because the sets of pixels for the cup, disc, and background are disjoint. Therefore, determining the extent of the optic disc also determines the extent of the optic cup and the background. This is most easily seen using the idealized fundus image in Figure 19, in which the optic cup is depicted in red, the optic disc in black, and the background

Figure 5.1: Fundus image

5.1 Converting an RGB Image to Grayscale

An RGB image is composed of three color channels: red, green, and blue. Each pixel in an RGB image is represented by a combination of these three intensities. In contrast, a grayscale image reduces this complexity by representing each pixel with a single intensity value, reflecting its brightness.

The conversion process involves calculating a weighted sum of the red, green, and blue channels. This formula, commonly used in image processing, is:

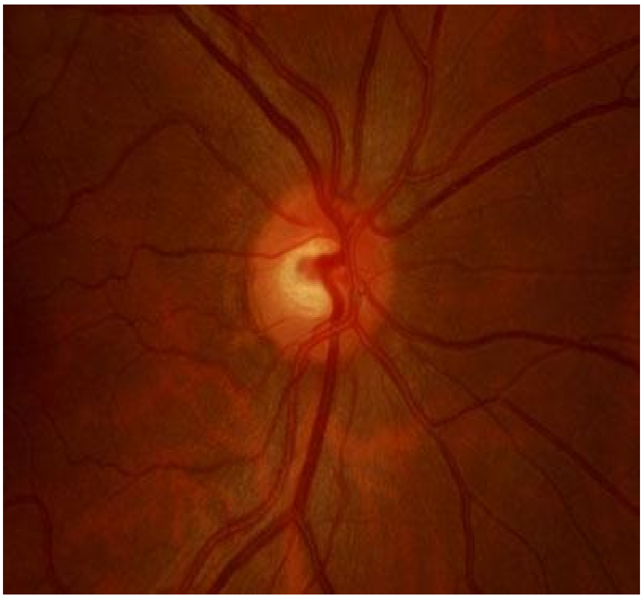


Figure 5.1: RGB Image

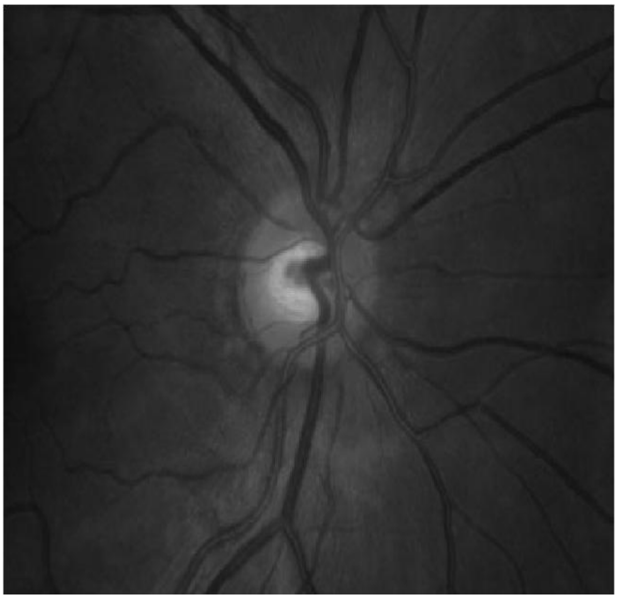


Figure 5.2: Grayscale Image

5.2. Thresholding for Feature Extraction

In many image processing applications, **thresholding** is used to highlight specific features within an image, such as objects, edges, or regions of interest (ROI). This is often done by setting a particular intensity threshold.

This helps in isolating important features, such as objects, shapes, or patterns, and simplifying further processing (e.g., measurements, counting, shape recognition).

5.3. Object Detection and Segmentation

In many computer vision tasks, the goal is to **segment** or detect specific objects in an image. A binary image makes this task much easier because:

- By converting to binary, it becomes easier to distinguish between objects and the background. The foreground (objects) can be set to white, and the background to black.
- **Segmentation** involves dividing an image into regions that correspond to different objects or boundaries. In binary images, these regions are represented as white regions on a black background.

5.4. Image Thresholding for Binary Classification

In applications like **glaucoma detection** or **face detection**, it's often necessary to isolate certain structures within an image, such as the optic disc, blood vessels, or eyes, from the background or surrounding tissue.

- Grayscale images contain both useful information (the objects of interest) and background noise.
- **Thresholding** helps in extracting only the structures of interest by converting the image into a binary format where:
    - **Foreground (objects of interest)** is assigned a value of 1 (white).
    - **Background** is assigned a value of 0 (black).

5.5. Data Reduction and Storage Efficiency

- **Grayscale images** consume more memory because each pixel requires more bits to represent the intensity (usually 8 bits for 256 grayscale levels, or more if it's a higher bit depth).
- **Binary images** use just one bit per pixel (either 0 or 1), dramatically reducing memory requirements.

5.6. Image Morphological Operations

In image processing, **morphological operations** (such as dilation, erosion, opening, and closing) are widely used for:

- Removing small noise.
- Filling holes in objects.
- Highlighting the shape of structures.

5.7. Pattern Recognition and Classification

- In **pattern recognition** tasks (e.g., character recognition, shape detection), binary images are often the input format. This is because binary images reduce the complexity of the data, making it easier to apply machine learning algorithms or algorithms like **template matching**.

5.8. Edge Detection

When detecting edges (where there is a significant change in intensity), a binary image can highlight the boundaries more clearly. For example, using an edge detection operator like **Canny**, the output can be a binary image where edges are represented as white pixels and the non-edge regions as black pixels.

5.9. Preparing for Further Image Processing or Machine Learning

Once a binary image has been obtained, it's often easier to apply more advanced image processing techniques or **machine learning models**. Many models, especially early-stage models like those based on **convolutional neural networks (CNNs)**, expect binary images or binary features as input data for certain tasks (e.g., object detection, segmentation).

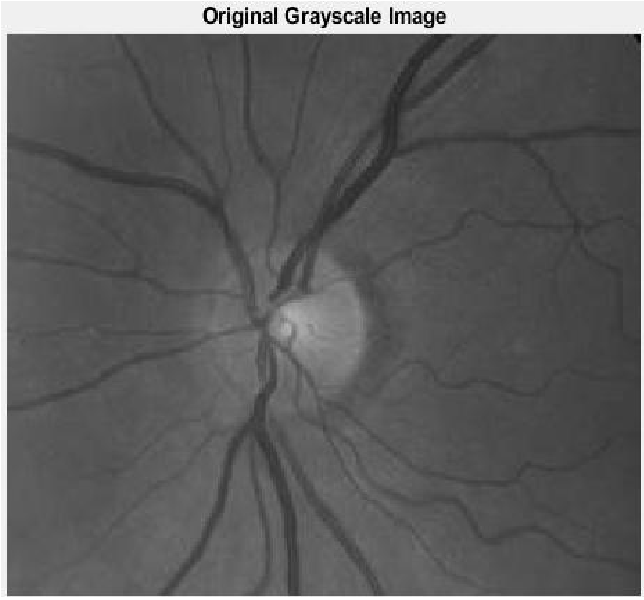


Figure 5.3 Gray scale image

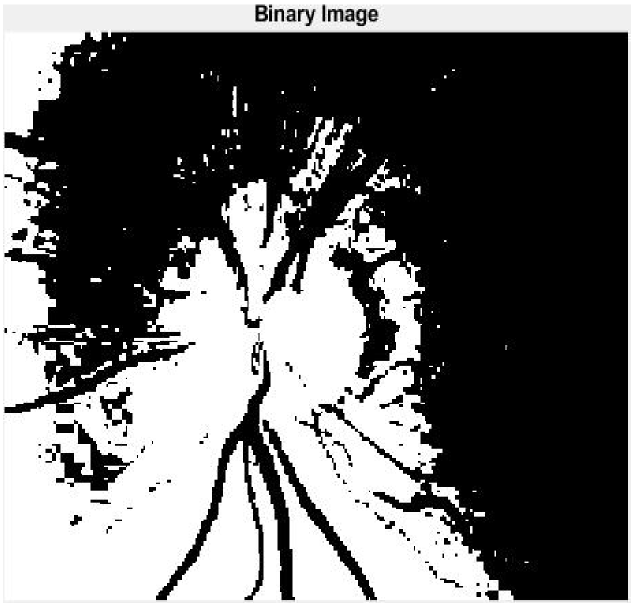


Figure 5.4 Binary image

5.10 Median filter to Remove Noise

The **median filter** is a non-linear digital filtering technique used to remove noise from signals or images. It is particularly effective at preserving edges while filtering out noise, making it one of the most widely used methods for image de noising, especially when the noise is of a salt-and-pepper type.

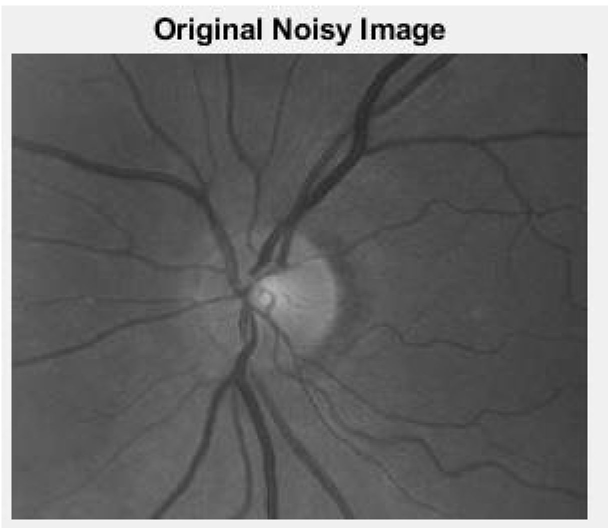


Figure 5.5: Noisy Image

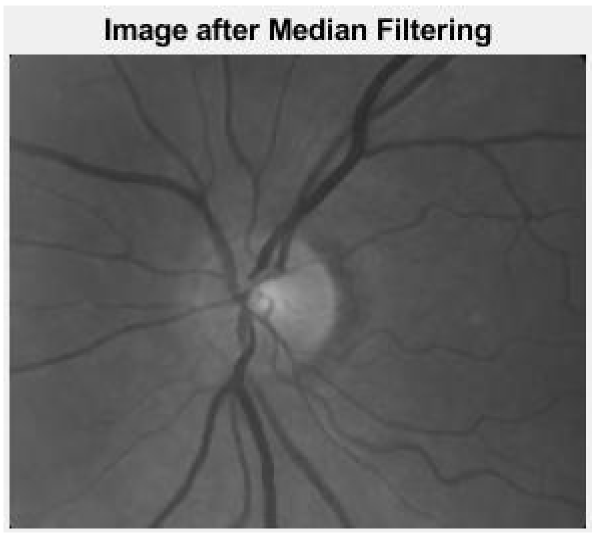
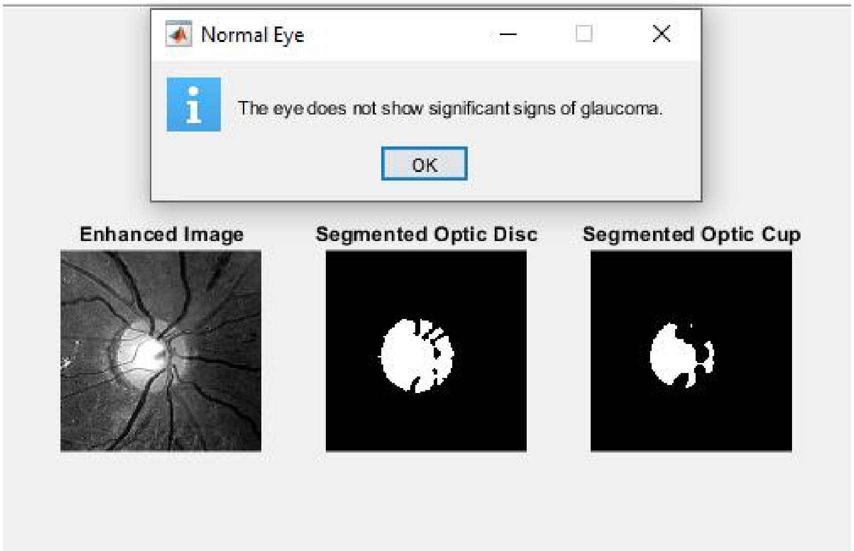


Figure 5.6 Filter Image

5.4 Difference between Noisy Image and Noiseless Image



Cup-to-Disc Ratio (CDR): 0.58116 The eye does not shows signs of glaucoma (High CDR).

Chapter 6

6.1 Conclusion

In this thesis, we explored the potential of using the Cup-to-Disc Ratio (CDR) as a key metric for the detection and diagnosis of glaucoma. By analysing retinal images and correlating the CDR values with clinical glaucoma indicators, we were able to demonstrate that CDR serves as a reliable and non-invasive measure for early glaucoma detection. The study further confirmed that a higher CDR value often correlates with the progression of glaucoma, offering a promising method for monitoring the disease over time. This approach has significant potential for improving diagnostic accuracy, especially in settings where advanced imaging equipment or specialist expertise may not be available.

The results from our analysis provide strong evidence that the CDR value can be an effective tool for identifying glaucoma, but it is also essential to note that it should be used in conjunction with other clinical assessments, such as intraocular pressure (IOP) measurements and visual field tests, to ensure comprehensive patient evaluation.

6.2 Future Work

While our findings provide a solid foundation for glaucoma detection using CDR values, there are several avenues for future research. One area of improvement lies in the integration of artificial intelligence (AI) and machine learning (ML) models to enhance the precision of CDR measurement and interpretation. Future studies could focus on automating the CDR calculation from retinal images to minimize human error and increase scalability for large patient populations. Additionally, further investigations could explore the use of CDR in conjunction with other biomarkers or advanced imaging techniques, such as optical coherence tomography (OCT) or fundus photography, to create a multi-faceted diagnostic model. This could lead to more accurate and early detection of glaucoma, as well as improved treatment outcomes.

Chapter 7

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