Automated Glaucoma Detection using CDR Method on Fundus Images using Fuzzy Logic

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Declaration

I certify that this research work titled "*Automated Glaucoma Detection using CDR Method on Fundus Images using Fuzzy Logic*" is my own work. The work has not been presented elsewhere for assessment. I have properly acknowledged / referred the material that has been used from other sources.

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This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

Acknowledgement

I am thankful to my creator Allah Almighty to have guided me throughout this work at every step, for giving me strength and for every new thought that setup in my mind to improve and then complete it.

I pay my special thanks to my beloved parents who remained my support and motivation in every sphere of my life. After Allah Almighty's blessings, it's only because of their prayers and unending efforts that I am standing at a place where I am today.

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Abstract

Glaucoma is one of the severe visual diseases and the leading cause of irreversible blindness by affecting the optic nerve fibre and astrocytes in human eye. Early diagnosis and cure can play vital role in the lives of patients, and it is possible only if Glaucoma suspected patients are checked periodically by Ophthalmologist. Various clinical examination techniques are available that are time consuming, require multiple resources and ophthalmologist involvement. Therefore, an automated system is preferred that support Ophthalmologist by its minimum involvement and accurate diagnosis.

Digital retinal based fundus imaging is one of the sources available in Ophthalmology that is used in detecting most of the eye related diseases including Glaucoma with the help of various image processing techniques.

Fuzzy logic is a technique that can manage uncertainty and imperfection of an image in a better way by representing it as a fuzzy set, thus producing accurate results.

In this research, a fully automated methodology for glaucoma detection from retinal fundus images using fuzzy logic is proposed. Cup-to-Disc Ratio (CDR), being the most accepted physiological parameter for glaucoma detection, is calculated by segmenting Optic Disc (OD) and Optic Cup (OC) using fuzzy logic, augmented with few morphological operations. Novel vector based approach is used for diameter calculation of OD and OC.

Key Words: *Glaucoma, Optic Nerve Head (ONH), Fundus Image, Cup-to-Disc Ratio (CDR), Fuzzy Logic, Image Enhancement, Edge Detection, Morphological Operations*

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CHAPTER 1

INTRODUCTION TO GLAUCOMA

The term glaucoma translates ‘clouded’ in Greek language. It is explained as a syndrome of physical or functional reliability of optic nerve which can be typically prevented or subsided by acceptable dropping of intraocular pressure (IOP). Prior to exploring it’s types, causes, assessment procedures and management of glaucoma, it is highly necessary to know fundamental anatomy of human eye along with working principles.

1.1 Anatomy of Human Eye

Though every single organ has its exceptional value in overall healthy functioning of human body, nevertheless human eye is graded by medical gurus as most complicated body part. At a glance, this small organ has numerous functioning parts. However, full understanding of human eye is even not claimed by classified ophthalmologists with confidence, yet wide-ranging anatomy is discussed in succeeding paras in order to understand it’s impending concepts associated to glaucoma.

1.1.1 Basis Definitions

- **Lens.** It is a spherical object in eye what is situated behind the cornea and it focuses light rays entering in eye on the retina.

- **Cornea.** It is clear part of eye what covers the iris and pupil and permits light to enter in eye is called Cornea. It allows an eye to provide sight.

- **Pupil.** Small rounded dark center of an eye that adjusts itself as per requirement to regulate quantity of light that reaches retina is called as Pupil.

- **Iris.** It is colored part of the eye what engulfs pupil is Iris. It is like a pigmented sheath which lies between cornea and lens. This part of eye acts as a diaphragm what enlarge or slender the pupil, therefore regulating amount of light that enters the eye.

- **Sclera.** It is external coat of the eyeball which forms distinguished white part of the eye and it covers optic nerve which lie at the back of the eyeball

- **Retina.** It is sensory film what lines the eye; images shaped by the lens is received by it and first transformed into signals and then transmitted to brain through optic nerve.
- **Optic Nerve.** It conveys electrical impulses from photoreceptor cells in the retina to the visual cortex which is situated in the brain.
- **Optic Nerve Head.** It is the rounded zone where the optic nerve enters to retina, and position of the eye's blind spot is known as optic nerve head. It is also called as optic disc.
- **Choroid.** It is layers of blood vessels which is situated amid sclera and the retina; its main purpose is to provide nutrition to back part of the eye.
- **Macula.** It is that portion of an eye lie near the center of the retina that allows to perceive the substances with much detail.
- **Fovea.** A lower side in the retina that comprises cones and delivers acute eyesight.
- **Vitreous Body.** It is part of eye which is between the lens and the retina encompassing of a clear jelly known as vitreous humor.
- **Ciliary Body.** It is that portion of eye that locates between the iris and the choroid. Main purposes of ciliary body are to house, aqueous hum or creation and keeping the lens at it's place.
- **Aqueous Humor.** It is fluid in between cornea and iris which is formed by ciliary body is called aqueous humor. Glaucoma roots trouble in draining this fluid and IOP build up.

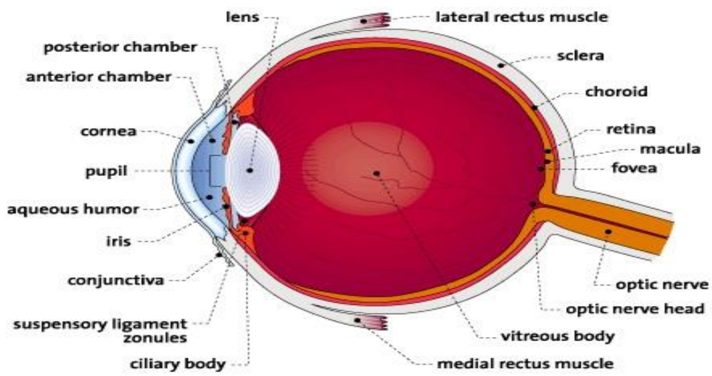


Figure 1.1: Human Eye Anatomy [1]

1.1.2 Working of an Eye

When we intend to look at some element, our eyes essentially focus image on retina, which translates this optical image into electrical signals and then transmit it to brain for explanation. This is an amazing and complicated process and we perform it continuously without trying.

1.1.3 Image Creation on Retina

It is interesting to know that when light ricochets from any object and reach back to the eye, it is essential to be bent for rays to reach at the retina and a focused image of an object is seen. Over here, four varied planes cause the light rays to bend when it arrives to the eye: cornea, lens, aqueous and vitreous humors. Human optical system can envisage numerous things at diverse ranges with the help of ciliary muscles. By looking at distant entities, the ciliary muscles contracts and the lens adopts trodden shape. While watching at close thing, these ciliary tissues again change shape and make the lens thickened. It suggests that eye is far superior to camera. Tuning of camera lens to focus on any object, complete lens is to be moved. Whereas, lens in the eye only changes its outline to adjust according to distance of entity. Moreover, to focus the light, our eye can control the amount of light entering into the eye. Iris regulates opening of pupil. In fuzzy light, iris makes pupil to expand more, allowing maximum light rays into an eye and vice versa.

1.1.4 Conversion into Electrical Signal

Whenever focused light pass through retinal portion of an eye, a chemical reaction happens in rod and cone cells which are light-sensitive. These rods contain a material known as **rhodopsin** and cones comprise a matter called as **color pigments**. These elements endure a modification which produces electrical impulses and then sent to brain via optic nerve.

1.1.5 Brain Interpretation

The moment theses electrical signals reach to brain, these at first scrutinize the information about light and its color. Brain then flip-flop the received image and fills missing information if essential. Whole process happens impulsively without disturbing human vision. Brain contains a visual reflex mechanism that accepts few of the information from the retina. Reflex system helps in reacting quickly to all the visual threats. By observing few objects reaching head on, this visual reflex mechanism commences processing and signals to the body to react timely in order to avoid any harm.

1.2 Retinal Diseases

Healthy retina ensures vigorous and accurate vision. Light coming from numerous object first reaches into the human eye via iris, which subsequently controls quantity of light and retina which is a thin film founding rear part of an eye and collects it and focus onto the retina. Retina converts this focused image into electrical impulses and optic nerves convey these to head.

Ophthalmologist enlarges pupil during clinical examination using many medicines [2]. After this he uses a special magnifying lens for retinal examination. Dilation converses after few hours.

Our eye is considered as the only body organ where doctors can directly observe arteries and deep veins with the help of ophthalmoscope. Learning these blood vessels, the doctors can inspect effects of diseases like hypertension and atherosclerosis on blood vessels in the body. Retinal syndromes are many in number having numerous causes to ensue. Glaucoma is one of these disorders.

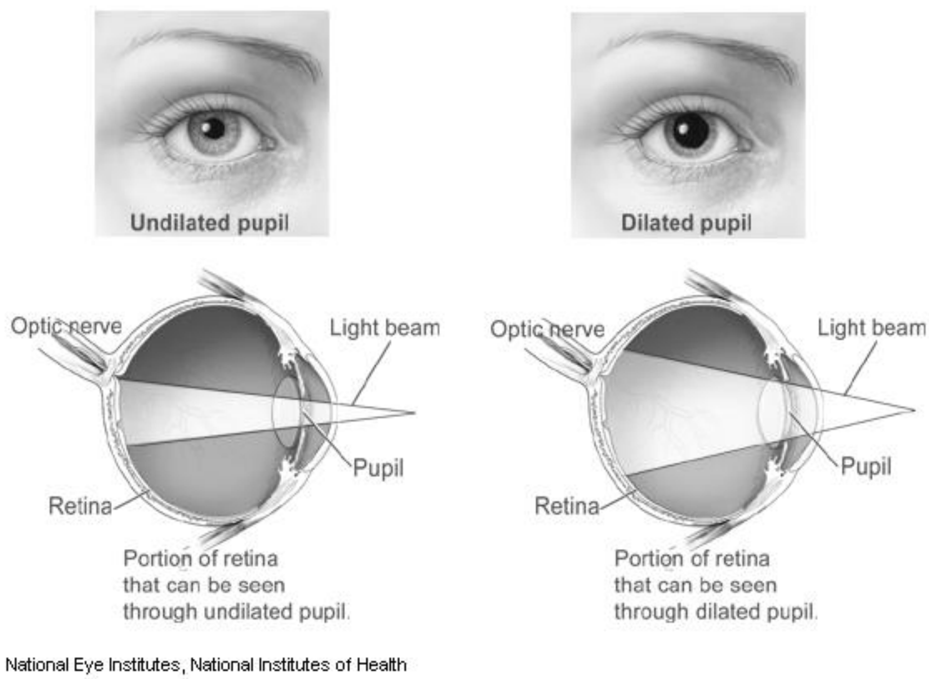


Figure 1.2: Dilated and Un-dilated Eyes [3]

1.2.1 Glaucoma

A poly faceted eye illness with particular features such as damaged optic nerves and irreversible loss of visual field. In glaucoma the bordering vision is commonly affected in early stage. Disparities in vision may be so slow that they are not noticed till a lot of vision loss has already occurred. If glaucoma is not treated properly, then central vision will also be lessened and then gone. Visual damage from glaucoma is mostly noticed in such manner. Encouraging is that glaucoma can be handled if noticed initially and through treatment most people with glaucoma may evade losing vision.

1.2.2 Causes of Glaucoma

It was opined previously that high pressure inside eye is main reason of optic nerves impairment, which is called as intra-ocular pressure or IOP, as well. Although IOP is a clear risk factor but research tells us that there are additional factors too what are involved as even those people having normal IOP also experience vision loss due to glaucoma [4]. Other common reasons are: -

- Genetics
- Damage to eye that harm iris
- Side effect of medicines
- Iris inflammation or tumor

1.2.3 Types of Glaucoma

Raised IOP person is a glaucoma *suspect*, as the high eye pressure may originates glaucoma. S*uspect* too include those who have other signs that may now or at any time in the future, give increase to glaucoma. e.g., a family history of glaucoma or a suspicious optic nerve may lead someone vulnerable to glaucoma.

It results in loss of vision when the eye pressure rises to a point that it causes permanent impairment to the optic nerve while first effecting the side vision. This may be slow and invisible till a considerable loss of vision have taken place.

It may be classified into three main types that can be further divided into primary and secondary categories. These include: -

a) Open angle
b) Close angle
c) Developmental

1.2.3.1 Open-Angle Glaucoma

It is the most common type and is considered to be the Open angle glaucoma that accounts for at least 90% of all cases. It results from the gradual obstruction of drainage canals, causing an increase in eye pressure (Figure 1.3). It has a wide and open angle between the cornea and the iris (Figure 1.4). Development of this type is slow but lifelong ailment. Symptoms and damage of this type goes unobserved and thus vision loss.

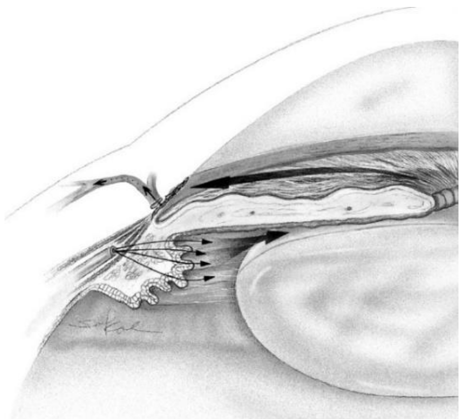


Figure 1.3: Open-Angle Glaucoma - reduced aqueous humor flow from Schlemm's canal [4]

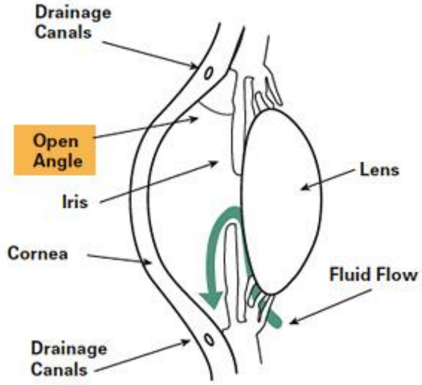


Figure 1.4: Open-Angle Glaucoma [5]

Width of an angle between the iris and cornea in Open angle type remain as per the normal specification consequently it is called Open angle. It is called as primary or chronic glaucoma too.

1.2.3.2 Angle-Closure Glaucoma

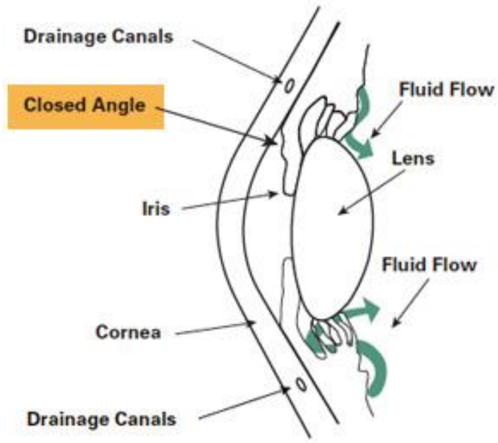


Figure 1.5: Angle-Closure Glaucoma [5]

This is another type which is less common in masses and is Angle-closure glaucoma. Trabecular meshwork is choked that result in an abrupt increase in IOP. Angle between cornea and iris gets narrower in this type. It progresses rapidly and the resulting indications and damage is very obvious thus requiring instant medical care. It is also known as narrow-angle or acute glaucoma because narrowness of angle between the iris and cornea.

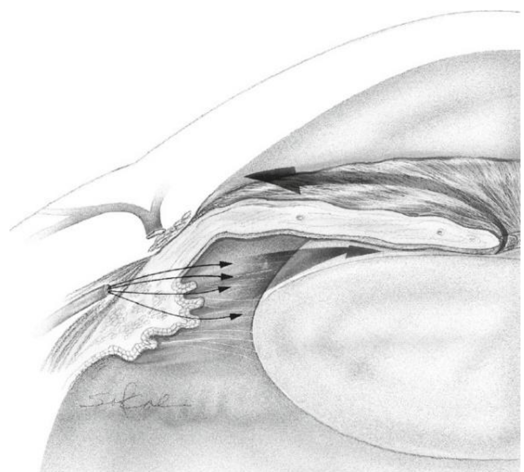


Figure 1.6: Angle-Closure Glaucoma - Iris covers the drainage canals – Outflow of aqueous humor is obstructed [4]

1.2.3.3 Developmental Glaucoma

It is also known as infantile or pediatric glaucoma and occurs in children and babies. It is diagnosed quite early i-e during first year of birth. This is an infrequent state which is triggered by improper growth of drainage system of an eye before birth and could be genetic. It leads to more IOP, which then harms the nerve fibers. Indications of this type are: -

- Vagueness of the cornea
- Photosensitivity, and
- Enlarged eyes

1.3 Optic Nerve Head and its Evaluation Procedure [6]

Glaucomatous optic neuropathy is part of all types. While detecting and managing, it is appropriate to understand that how the optic nerve head (ONH) is studied.

1.3.1 Clinical Examination of ONH

Numerous apparatuses are existing which are being utilized for investigating ONH, primarily comprises direct and indirect ophthalmoscope or lens along with a slit lamp as shown in Figure 1.7. It can be assessed ONH accurately with little training. ONH investigation being the painful process for the patients, time available for inspecting optic nerve head is often brief, consequently examiner must be sharp to make important observations. Pupil dilation helps in improving the rightness of diagnostics with these instruments. High technology and devices are available like confocal scanning laser ophthalmoscopy, OCT and scanning laser polarimetry which always augment the clinical investigation of retina and provide quantifiable readings.

(a) **(b)** **(c)**

Figure 1.7: (a) & (b) Direct & Indirect Ophthalmoscopes, **(c)** Slit lamp & posterior pole lens [7]

1.3.2 Characteristics of Normal ONH

Optic nerve head (ONH) is an oval shaped feature placed on retina having orange appearance, underneath which nerve fibers are millions in number pass over a mesh-like layer which is called lamina cribrosa. These fibers are then bundled together at the back of an eye to make an optic nerve which receipts signal to brain. These optic nerve fibers are dispersed asymmetrically over the retinal exterior as a thin layer having ‘feathery’ look, this can also be observed thoroughly in the nearby areas of an optic disc precisely above and below the disc. As the nerve fibers congregate on the edge of the optic disc they release over the scleral ring and then pass through its inner surface. This compressed stuffing of nerve fibers in amid optic disc and optic cup is mentioned as the neuro-retinal rim. Optic cup is the central yellowish region of optic disc. Cup boundary can be best segmented out with the help of blood vessels bends which happen because of entrance of these vessels into cup. Neuro-retinal rim follows ISNT rule which communicates that width of NRR is extreme on inferior side than superior side trailed by nasal side and thinnest on the temporal side. (Figure 1.8).

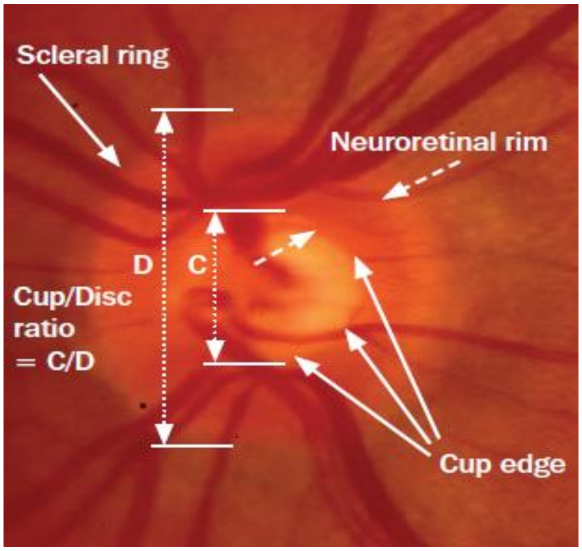


Figure 1.8: Normal optic nerve head [6]

1.3.3 Appearance of Glaucomatous ONH

Normal optic nerve head when affected, then it is named as Glaucomatous optic nerve head. This type of ONH comprise few peculiar features which can simply be assessed using existing clinical instruments by the specialists. List of these features are: -

- Generalized / focal enlargement of the cup.
- Enlarged cup to disc ratio (CDR)
- Disc outpouring
- Lessening of neuro-retinal rim
- Indiscretion of excavation between two eyes
- Damage of optic nerve fiber layer
- Para-papillary atrophy

- Dislocation of vascular bundle in the direction of nasal side [8]

1.3.4 Distinguishing Glaucomatous ONH from Normal

Apropos, specialists differentiate normal and glaucomatous ONH using succeeding protocol: -

- Pupil dilation is carried out
- Distinguish optic disc boundary and optic cup boundaries in order to find retinal rim
- Is neuro retinal rim follow the well-known rule of ISNT
- Does hemorrhage visible or not?
- Vertical cup to disc ratio (CDR) is assessed
- Optic nerve head size is measured
- Appraise RNFL (retinal nerve fiber layer)
- Annotation of the ONH is done
- Qualitatively examine the movement of vessel bundle towards nasal side

1.4 Screening of Glaucoma and its Importance

1.4.1 Clinical Procedure

To correctly diagnose glaucoma, a specialist gets help of certain clinical tests for wide-ranging inspection of an eye. Patients are advised to undergo dilated pupil eye investigation at least once in one to two years. Importance of screening cannot be overlooked as it is the only possible way of evading disease development. This investigation may include succeeding clinical tests:

1.4.1.1 Tonometry

It is known as the basic test wherein inside pressure of eyes are measured and recognized as intraocular pressure (IOP). Examples of tonometer comprise:

- A puff of air is emitted using ***noncontact tonometer***. Resistance faced by an eye is used to compute the eye pressure.
- Other technique usually used for the same purpose is ***applanation tonometer.*** An eye surface is touched after making it anesthetized and pressure is noticed that is important to flatten the cornea. This tonometer is known as very sensitive.
- Digital pen like apparatus is used to measure the eye pressure. It is called as ***electronic indentation method***, as well.

1.4.1.2 Pupil Dilation

In ordinary conditions pupil has a very small opening which is attuned as per exterior light settings. Using this opening light enters into the eye and make image of an object at retina. Because this opening is very inadequate therefore little portion of retina is exposed to be inspected by specialist for any aberration. Peculiar eye drops are used for expansion of pupils on momentary basis so that retina can be entirely seen during investigation.

1.4.1.3 Visual Field Testing

It is evident that glaucoma hinders the sight progressively commencing from fringe towards center consequently visual field testing is done to assess the area seen by forward looking eye. A spot is shown to the patient and on its basis specialist document it and find out the state of vision. A patient responds each and every time, whenever blinking of a light is seen that is noticeable in front.

1.4.1.4 Visual Acuity Test

Sharpness of a vision is calculated with the help of this test at varied positions. Visual charts are displayed and patients see them from a distance of 20-25 feet using several lens sizes.

1.4.1.5 Pachymetry

Another technique of assessing the pressure inside an eye. An apparatus creating ultrasonic waves is used for purpose by which cornea thickness is evaluated.

1.4.1.6 Ophthalmoscopy

Both types of ophthalmoscopes i.e. direct or indirect are the apparatuses which used in this screening method to inspect the interior surface of an eye via pupil. This test helps in detecting any damage of optic nerve head caused by the disease.

1.4.1.7 Gonioscopy

Iris becomes closer to the back of cornea in closed-angle glaucoma. Gonioscopy is a technique where a specialized apparatus is utilized to diagnose it in closed-angle by inspecting front part of the eye (forward chamber). It governs location of an iris that weather it is closer than normal or not.

1.4.1.8 Optic Nerve Imaging

Tomography is a method being used to register numerous diseases during investigations and prognosis stages. After some time, optic nerve head goes through physical changes due to presence of aberrations. Current imaging procedures used in ophthalmology to notice these variations are: -

- Stereo photographs of ONH
- Heidelberg Retinal Tomography or HRT
- Scanning laser polarimetry
- Fundus imagery
- Optical coherence tomography (OCT)

Apropos methods are noninvasive thus painless. An ophthalmologist decides appropriate technique(s) to be used as per state of patient and stage of glaucoma.

1.4.2 Automated Procedure

Procedure of medical imaging widely utilized in these days to record existing state of ONH instead of investigating retina in real time and identify / diagnose disorder in less time. This facilitates specialists a real chance to register and compare ailment development in optic nerve head. Moreover, researchers are working on reaping optimum advantages of these images in automated finding of those ailments whose apparent presence can be segmented out and identified by utilizing various design / feature identification procedures.

Computerized technique of screening this disease can assist specialist by carrying out large level screening of patients and separating suspected eyes with normal ones. This method will not only reduce the load over inadequate number of available specialists in existing times but also play a better role in initial finding of disease affected patients. This is the sole key available to evade this irreparable disease.

1.5 Treatment of Glaucoma

Handling of this disease only rest on its type with which patient being diagnosed, its condition and then response shown by patient to explicit healing method.

Administration of glaucoma can be done by implementing many treatment approaches. Mostly and very extensive used treatment choices given by specialists in upward order are as follows: -

- **Medication**
  - Main medication – utilizing eye drops
  - Secondary medication – which uses pills / tablets

- **Surgical Methods**
  - Non-invasive or Laser surgery
  - Invasive or traditional surgery
- **Blend of above-mentioned procedures**

Quick and consistent disease administration is very important for avoiding vision-threatening harm. Each medicine has few likely side effects though exemptions are always there which face very tiny or no side effects thus it is common effort which is to assumed by patient and advisor to fight successfully against this disease while fighting this war.

1.5.1 Medication

Almost every type of handling used for this disease is primarily embattled at reducing IOP therefore consistent medication is actually very significant. Eye drops are in beginning utilized and they absorbed into bloodstream. In some conditions if eye drops are not effective curative pills could be included in addition to eye drops. These tablets aid to turn down the eye's passage and reduces the formation of fluid.

1.5.2 Surgical Measures

Occasionally utilizing medicine which do not create expected results or have intolerable after effects then specialist go to succeeding phase and that include surgical technique.

Laser surgery is a transitional step amid medication and existing surgical measures. It has developed more and more common though the lasting success rates are variable. Laser surgery is comparatively a simpler technique thus can be taken on in either clinic or outpatient treatment. It is usually accomplished within 10 to 15 minutes and is trouble-free. Extensively used types of laser surgery being done for this disease are as follows: -

- Argon Laser Trabeculoplasty (ALT)
- Selective Laser Trabeculoplasty (SLT)
- Laser Peripheral Iridotomy (LPI)

While treatment and healings processes based on laser do not adequately lower eye pressure then as a last resort consultant suggest existing conventional treatment. While utilizing this method primary target of any specialist is to drain undue fluid inside eye by forming a passage in the sclera which resultantly reduce inside pressure and avoid nerve harm. Mostly utilized of these procedures are as follows: -

- Trabeculectomy

- Drainage Implant Surgery
- Nonpenetrating Surgery

Traditional existing treatment is a painful method nevertheless around 50% affected improves successfully from the disease after undertaking surgical treatment and even no longer need medicines for considerable period of time [9].

1.6 DIGITAL FUNDUS IMAGERY

1.6.1 Overview

Linguistic connotation of fundus is taken as ‘bottom’. *In ophthalmology the part of an eyeball in front of pupil is denoted as the fundus.* By having a snap of rear far end of an eye that is called fundus too, falls under the field *fundus photography*. Specialized fundus cameras are used in fundus photography which contains a complex microscope fixed to a flash aided camera. Primary building frame of eye i.e. whole retina, optic nerve head and macula can be envisaged on a fundus photo. Colored filters or specialized dyes may be used in fundus picturization.

Because of revolution in technology in previous century, fundus picturization has seen lot of developments in its systems. As latest modern technology encompasses fundus photography and more stimulating to fabricators to enhance it to clinical criteria, consequently restricted number of firms are available in business that produce this apparatus. Topcon, Canon, Nidek, Kowa, Zeiss, CSO and Center Vue are midst those few firms of fundus camera.

Figure 1.9: Fundus Images - (left) right eye, (right) left eye [10]

Figure 1.9 above illustrates standard fundus pictures of both eyes seen from front. Every image in which blood vessels are bundled in the direction of right side are pictures of person's right eye. Every fundus has no sign of ailment or pathology. In all image macula lie in middle of the retina every time, while optic disc is situated in the direction of nasal side. Fundus picturization registers retina. Imaging retina can be achieved directly as pupil is utilized as an entrance and exit point for light rays approaching from fundus camera into eye.

Figure 1.10: Fundus Camera [11]

1.6.2 Optical Principle of Fundus Camera

Fundus camera is a precise optical microscope attached with distinctive optical procedure [12]. Its optical design is built on the system called in ophthalmology as indirect ophthalmoscope. Angle of sight of lens is a vital characteristic in fundus cameras. Standard angle of view (30°), generates a film image 2.5 times magnified than actual image, however wide-angle cameras shoots snaps in the range of 45° to 140°. Wide angle cameras give proportionally fewer retinal magnification. Array of angle of sight of narrow angle fundus camera is 20° or less.

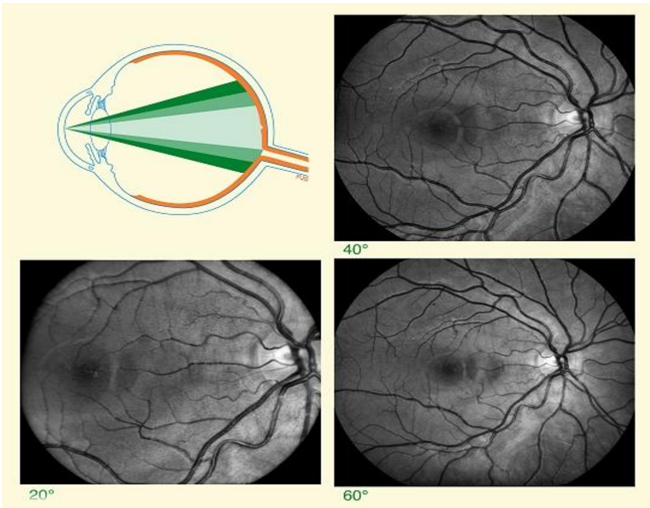


Figure 1.11: Angle of View – Fundus Camera [13]

To generate light electronic flash is utilized, which is passed from a set of filters and projected on top of a circular reflective glass. Successive lenses are utilized to focus its light which gets reflected by the mirror. Topmost lens possesses a mask, what forms light into doughnut type shape. This peculiar type of light is then reflected onto rounded reflective glass with a central aperture, leaving this camera through objective lens and go in eye through pupil. Highly significant contemplation in this technique is about illumination arrangement and object needed to be picturized are correctly aligned and focused. Resultant picture of retina trails central un-illuminated part of the doughnut and leaves cornea. Light remains through central aperture of earlier defined mirror, through astigmatic rectification device and diopter compensation lenses, and then back to single lens reflex camera arrangement what retransmits light onto capturing instrument, may it a film or a digital CCD.

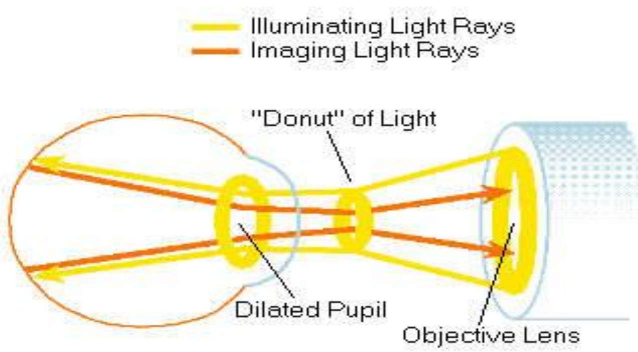


Figure 1.12: Doughnut of Light Formation [13]

1.6.3 Modes – Resolve Artifacts in Imageries

Open market available gadgets utilized for digital fundus imaging, is done by under mentioned methods of examination.

1.6.3.1 Color

Retina is inspected in color, in this type of examination, though illumination of retina is done through the white light.

1.6.3.2 Red Free Fundus Imagery

Diverse filters are utilized to inspect lesions and aberrations that occur onto the retina or in its vicinities. Green filter (~540-570 nm) is utilized to block wavelengths of red light. It generates an image what has better contrast for witnessing blood vessels and hemorrhages, soft lesions like drusen and exudates, and delicate structures such as RNFL defects and epi-retinal sheaths. Utilization of Red free imagery prior to angiography, is followed frequently as well taking it as a base line image.

1.6.3.4 Angiography

By adopting this method, a fluorescent dye is injected into blood stream to make it distinguished for imaging / snaping blood vessels flow on retina and adjacent tissues. This dye glosses a dissimilar color when light of specific wavelength approaches. While using this type of procedure, movement and pooling of blood vessels in unlike stages can be seized as dye flows over retina and choroid.

1.6.3.5 Sodium Fluorescein Angiography

While using this procedure, imaging of retinal vascular disease and using blue excitation light of ~490 nm and fluoresces a yellow light of ~530 nm. Repeatedly it is being utilized to image Cystoid Macular edema and Diabetic Retinopathy amongst all rest.

1.6.3.6 Indocyanine Green Angiography

IR diode laser of 805 mm and filters that allow light with wavelength of 500 – 810 nm are being utilized in this technique for picturization. This procedure is mainly employed for imaging deeper choroidal ailments. Indocyanine Green Angiography is suitable for seeing choroidal vessel out pouching, anomalous vessels delivering ocular tumors and hyper permeable vessels amid other illnesses.

1.6.3.7 Stereo Fundus Photography

Latest improvements in digital imagery and 3-dimensional monitors have caught eyes of manufacturers to include this technology in photographic equipment. Latest progress has made simultaneous photography of retina from numerous angles which could have been conceived and then results through producing 3-dimensional image. While utilizing this method, image can deliver improved information about surface looks of retina and results in improved investigation.

1.6.4 Resolution of Artifacts in Fundus Imagery

Errors in objects do occur in fundus photography during snaping retinal images what are not needed. Due to these objects, affect image quality consequently patient help in this context is of very important to curtail artifacts. Prior to taking images, clinicians must convey patient about Dos and Don’ts. They must check that configuration and camera controls setting and decision making about film choice is precise. Above and beyond, adopting all these safeguards, there still occur few objects which are not very conspicuous and cannot be recognized till imagery is taken place. Generally, such objects happen due to mechanical glitches in camera or naturally tiny sized pupil of patient.

Apart this basis, blur images could be dry eyes of patient. For these cases actions like blinking of an eye quite a few times must be taken to lubricate eye prior to taking snaps. Examiner taking image has to be attentive and reliable in approving exact alignment. White dots should be in clear focus and aligned with pupil beforehand while pressing alignment button. Joystick must be utilized efficiently to focus retinal image. As soon as image is clearly focused only then procedure is finalized and image can be seized.

1.6.5 Recording & Interpretation

While capturing fundus image, patients put chin at rest available in front and adjust forehead against bar of fundus camera. After this cameraman perform essential alignment and focus retina. While pressing shutter button a flash is fired that eventually takes fundus picture.

Fundus photography is record of retinal looks. One fundus picture is comparable to hundreds of words that a specialist is needed to explain any specific ailment of a patient. These images permit specialists to intensely go into the specifics of such ailments in which prompt verdict could lead in the direction of wrong analyses. It further offers a chance to specialists to refer associates those cases in which retinal conclusions are intricate.

1.6.6 Advantages & Disadvantages

While an innovative technology where there are many benefits of fundus imaging, there are some restrictions, too. These are summarily explained as under: -

1.6.6.1 Advantages

- Easy to handle hence do not need any dedicated training to become specialist
- Greater area of retina can be seen in comparison to ophthalmoscopy
- No expansion of pupil takes place
- Minor invasive procedure than other existing measures

- Improved patient acceptance
- Pictures can be kept in database for succeeding usage
- Progress of ailments can be supervised over time and supportive for better administration plans
- Diverse filters and dyes commercially obtainable to allow for many types of tests

1.6.6.2 Disadvantages

- Picture generated by fundus camera is two dimensional
- Problem in witnessing and judging aberrations (e.g. cotton wool spots) due to lack of depth evaluation on images
- Little amplification and lucidity in pictures in comparison to ophthalmoscopy
- Some opaqueness in eye which may be a result of any ailment like cataract affects image quality
- Objects normally cause bizarre pictures

1.6.7 Future Advancements

Fundus imagery is established to be pivotal in detecting and treating patients in Ophthalmology. Current research work has exhibited that computer-aided ailment finding and study of human retinal fundus has remained a valuable instrument for the ophthalmologists. It has not only acted as a accompaniment to the prevailing procedures but also lessens the problem of less available specialist vis a vis number of patients. In upcoming days, it would be taken as a beneficial means for computerized finding of ailments and mass displaying of patients for early detects of numerous perilous syndromes.

CHAPTER – 2

INTRODUCTION TO IMAGE PROCESSING AND FUZZY LOGIC

2.1 Image Processing Overview

Image processing is a tool that is used to perform operations on an image, so to get an enhanced image or for extracting any desired and useful information. In this processing input is always an image and output is whatever is desired. It may be image or any characteristics/features associated with that image. In this technological era, image processing is one of the fast rising techniques. In engineering and computer science disciplines, it is forming the base everywhere and in every subject.

Mainly Image processing can be sub-divided in following three steps:

- Image importing using image acquisition toolbox
- Manipulation and analysis of the image for desired results
- Output that can be any altered image or any report based on image analysis or any feature

Two main types of methods are used for image processing i.e. analogue and digital image processing. Analogue image processing is the one which can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing is a tool that is used in analysis and manipulation of the soft material like digital images by using computers. Digital image processing can be mainly divided in three general phases that undergo digital techniques. These are image pre-processing, image enhancement, and image information extraction.

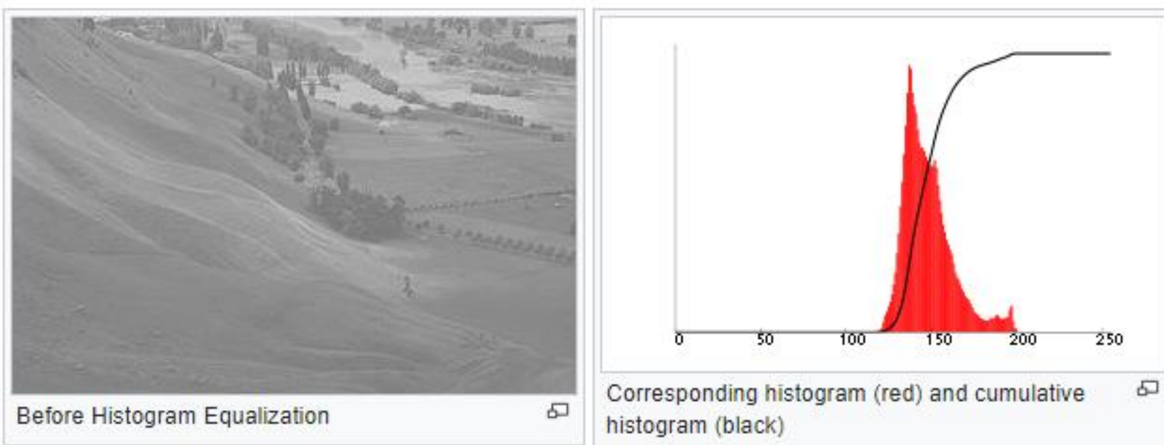
Image processing is subjective in nature and has various techniques that include image enhancement, contrast enhancement, histogram equalization, Thresholding, image cropping, resizing, morphological operations, filtering etc.

2.1.1 Image Enhancement

Image enhancement techniques are being extensively used in many applications of image processing where the images information to depth is required and essential for human understanding. Contrast is one of the most important parameter in any subjective valuation of image quality. Difference of luminance reflected from two adjacent surfaces is termed as contrast. In simple words, it is the difference in visual properties that makes one object different from other objects and the background. Visually, contrast is checked by the difference in the color and brightness of one object with another. In comparison to absolute luminance, contrast is more visible to human visual system; therefore, the world is perceived similarly regardless of the considerable changes in illumination conditions. Many algorithms for achieving contrast enhancement are there and are being applied to problems in image processing.

2.1.1.1 Histogram Equalization

Graphical representation of the intensity distribution of any image is termed as histogram. In simple words, graph represents the number of pixels against every intensity value of image. Histogram Equalization is image processing technique that is used for improving/enhancement of contrast in images. It is accomplished by efficiently spreading out intensity values, i.e. to stretch the intensity range of the image. Global contrast of image is usually enhanced by this technique. Due to this areas of lower local contrast gain a higher contrast.



Before Histogram Equalization

Corresponding histogram (red) and cumulative histogram (black)

Figure 2.1: Image with Poor Contrast

In figure 2.1 above, a low contrast image is shown. X-axis of graphical section is representing the tonal scale (black at the left and white at the right), and Y-axis is representing number of pixels in an image. Here, the graph shows the number of pixels for every intensity level (from black to white). Peak shows maximum number of pixel have that certain brightness level and it is higher. Contrast enhancement / histogram equalization technique is applied to spread out intensity values and result is shown is figure 2.2 below.

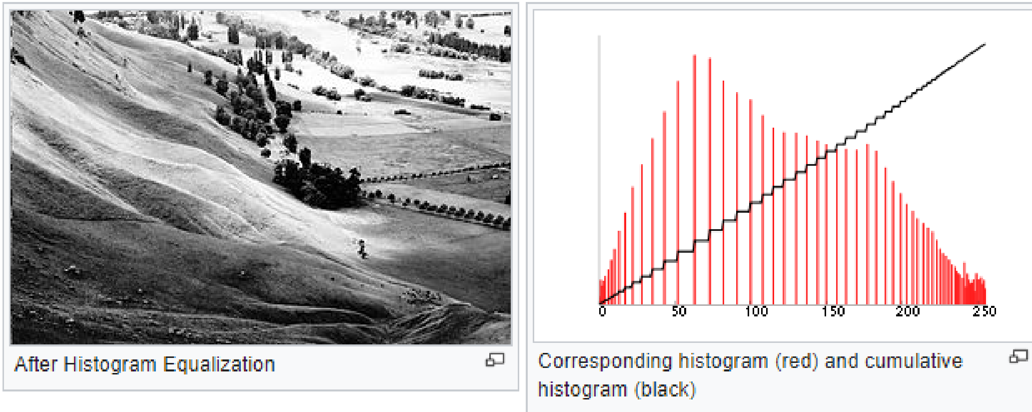


Figure 2.2: Image after Histogram Equalization

2.1.1.2 Adaptive Histogram Equalization

Adaptive Histogram Equalization is different from ordinary histogram equalization. In adaptive method several histograms are computed, each histogram corresponds to a distinct part of the image, and then lightness values of the image are redistributed. Hence it is suitable for improvement of local contrast and enhancement of edges in each part of an image.

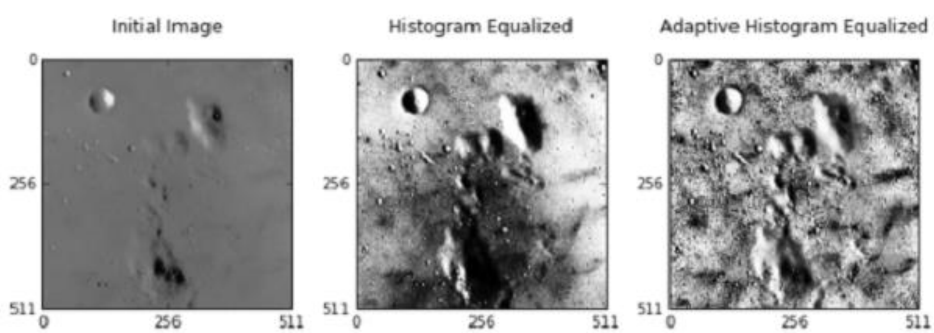


Figure 2.3: Adaptive Histogram Equalization

2.1.1.3 Contrastive Limited Adaptive Equalization

Contrast Limited Adaptive Histogram Equalization (CLAHE) is different from adaptive histogram equalization. Difference lies in its contrast limiting. In first case, transformation function is derived after application of contrast limiting to each neighborhood. One advantage of CLAHE is that it prevents the over amplification of noise whereas adaptive histogram equalization give rise to noise.

Figure 2.4: Contrast Limited Adaptive Histogram Equalization

2.1.2 Feature Extraction

In the areas of Image processing, feature plays a very significant role. Many image preprocessing techniques like conversion to binary, thresholding, resizing, normalization etc are applied on the sampled image before getting features. After that, feature extraction techniques are applied to get required features. And the same then can be useful for classification and recognition of images. Feature extraction is basically image data representation of the required parts of an image as a compact feature vector. In the past, this was being done using specialized feature detection, feature extraction, and feature matching algorithms and techniques. Now-a-days, deep learning is dominant in image and video analysis, and has become known for its ability to take raw image data as input, skipping the feature extraction step. Regardless of which approach you take, computer vision applications such as image registration, object detection and classification, and content-based image retrieval, all require effective representation of image features – either implicitly by the first layers of a deep network, or explicitly applying some of the longstanding image feature extraction techniques.

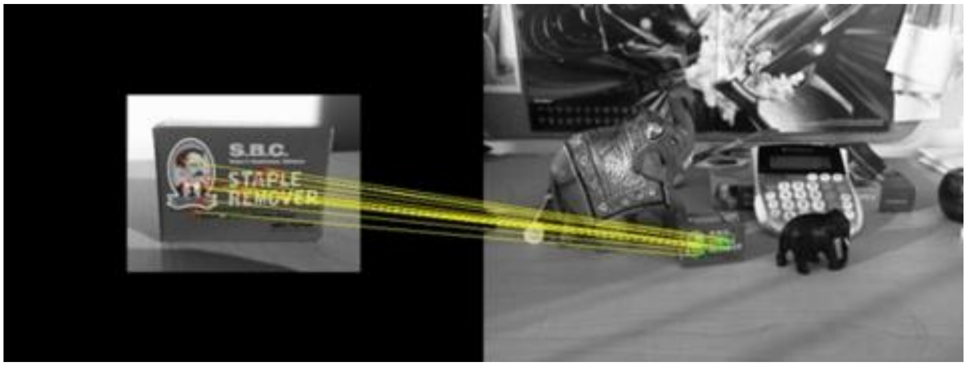


Figure 2.5: Object detection (left) in a cluttered scene (right) using a combination of feature detection, feature extraction, and matching

2.1.3 Edge Detection

Edge detection is an image processing technique that is used for finding the boundaries of objects within image. Discontinuities in brightness makes the base for edge detection. In many areas of image processing, computer vision, and machine vision edge detection is being used for image segmentation and data extraction. Common edge detection algorithms include Sobel, Canny, Prewitt, Roberts, Log and DWT methods [42]. Comparison of these techniques is as follows: -

Table 2.1: Comparison of Edge Detection Techniques [42]

Edge Detector	**Method**	**Advantages**	**Limitations**
Roberts detector	Gradient Based	1. Easy and simple to compute 2. Detect edges along with their orientation	1. These are very noise sensitive 2. Edge detection is comparatively inaccurate 3. Reliability is less
Sobel detector	Gradient Based	1. Easy and simple to compute. 2. Detect edges along with their orientation	1. These are very noise sensitive 2. Edge detection is comparatively inaccurate 3. Reliability is less
Prewitt detector	Gradient Based	1. Easy and simple to compute. 2. Detect edges along with their orientation	1. These are very noise sensitive 2. Edge detection is comparatively inaccurate 3. Reliability is less

Canny detector	Gaussian Based	1. Signal to noise ratio is improved. 2. Noisy pixel are more prone and sensitive i.e. suitable for noisy images 3. Comparatively accurate	1. It is slow and complex 2. False zero crossing is there.
LoG detector	Gradient Based	1. Detection of edges and their orientation is simple as approximation of gradient magnitude is simple. 2. Fixed characteristics in all directions. 3. Wide area testing is possible around the pixel.	1. Around corners, curves and points where gray level intensity function varies, malfunctioning occurs 2.Increase is noise degrades edges magnitude
Discrete wavelet Transform	Wavelet based	1. High accuracy 2. Computation is less	1. Oriented application 2.Comparatively complicated

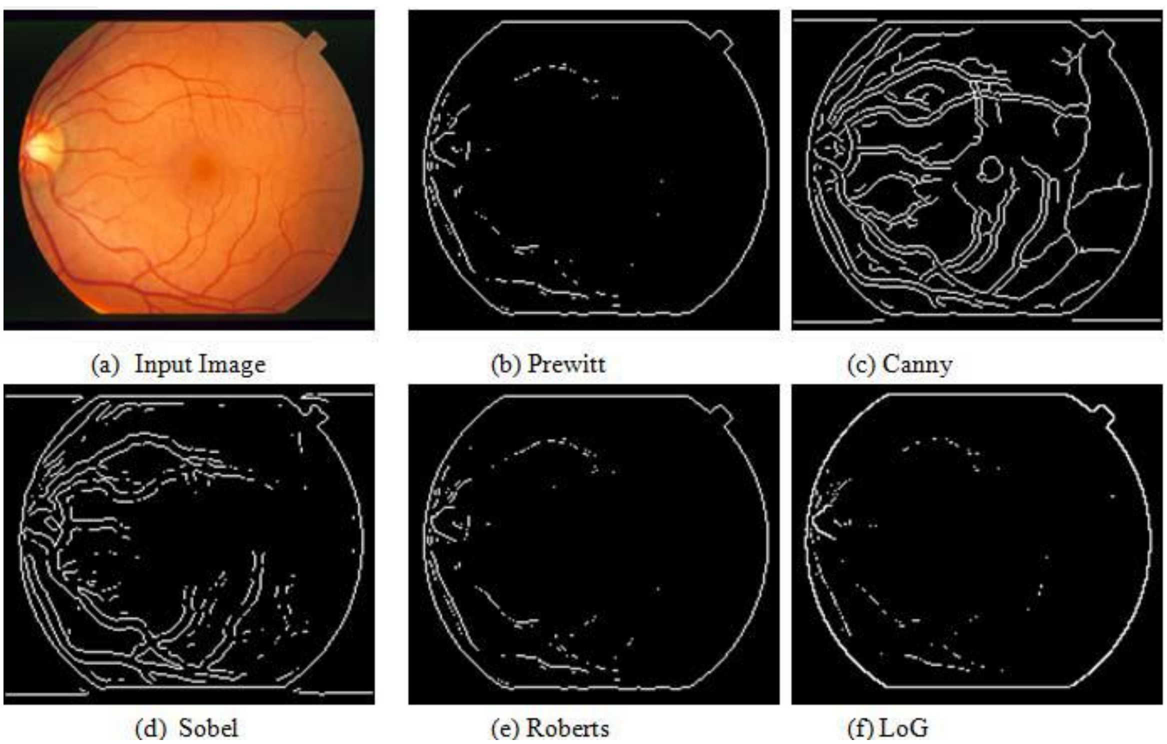


Figure 2.6: Edge Detection Results of various techniques over Retinal Fundus Image [42]

2.1.4 Morphological Operations

The word morphology basically forms a branch of biology which deals with animals and plants structure and forms. For the same reason, morphological operations are developed to alter the shape of object as required. Two basic operations are part of binary mathematical morphology. Operations are **Dilation** and **Erosion**. Several composite relations like **Closing** and **Opening** are also there.

Dilation is expansion of the connected sets of 1s in a binary image. It has applications in the fields of growing features, filling holes and gaps. Dilation can repair breaks and intrusions.

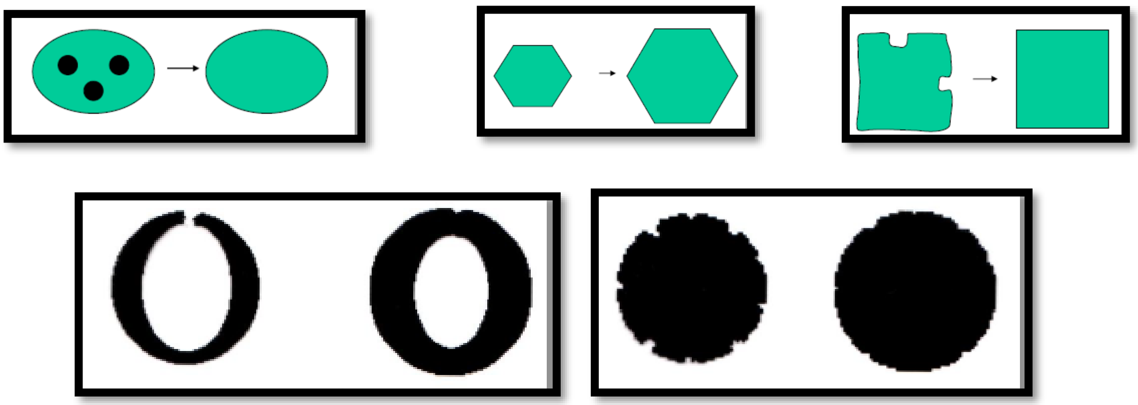


Figure 2.7: Dilation Results

Erosion is shrinking of the connected sets of 1s in a binary image. It has applications in the fields of shrinking features, removing bridges branches and small protrusions. It can split joined objects and strip away extrusions.

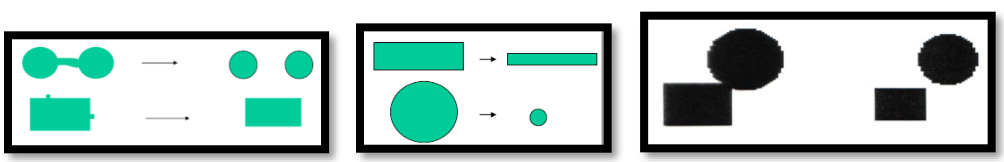


Figure 2.8: Erosion Results

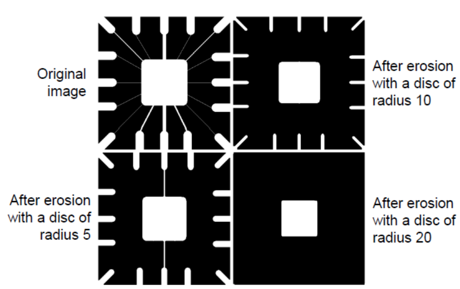


Figure 2.9: Erosion Example

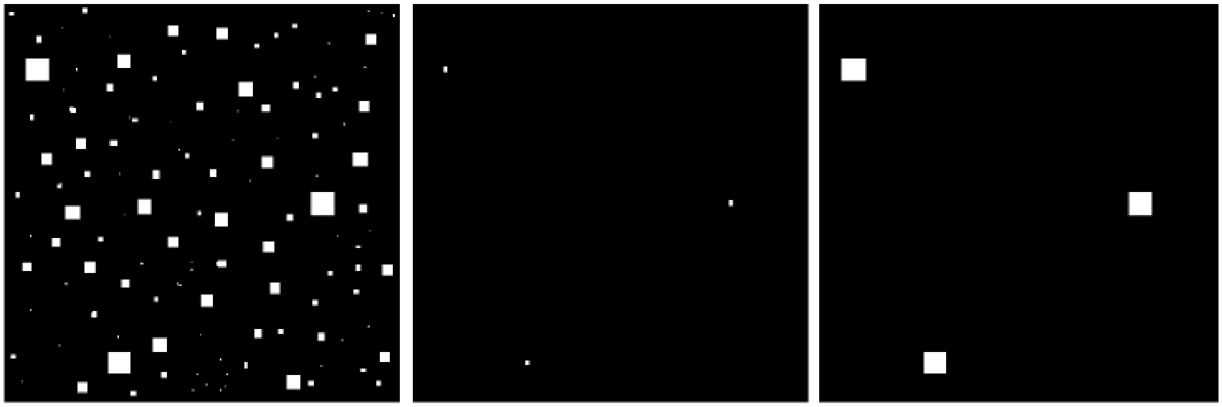


Figure 2.10: Application of Dilation and Erosion for removal of unwanted details

Opening is the compound operation of **Erosion followed by Dilation** (with the same structuring element).

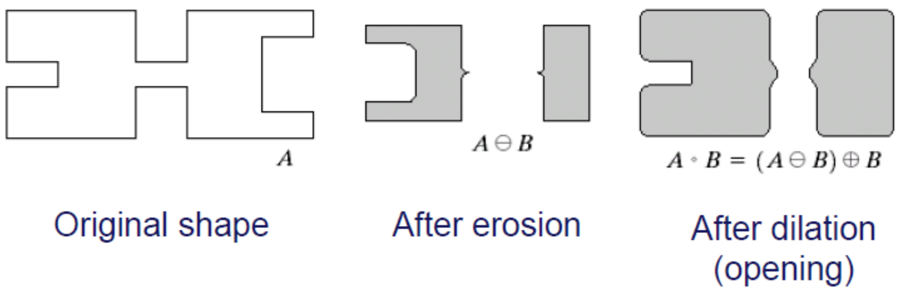


Figure 2.11: Opening

Closing is the compound operation of **Dilation followed by Erosion** (with the same structuring element).

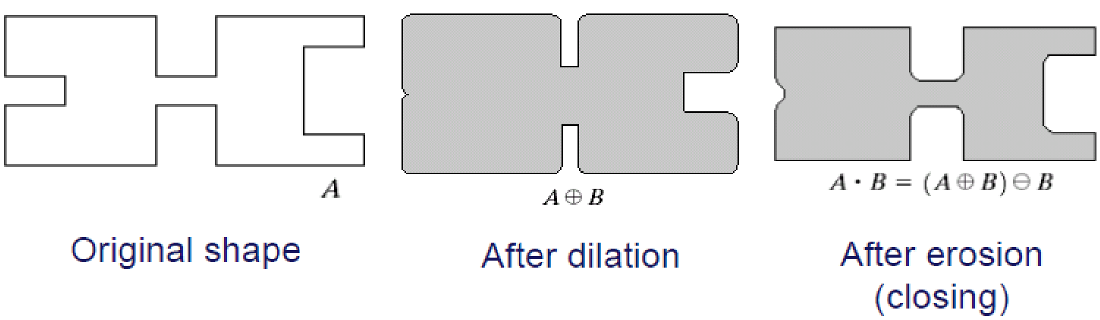


Figure 2.12: Closing

2.2 Fuzzy Logic

2.2.1 Overview

The word fuzzy can be defined as blurry, indistinct, imprecisely defined, confused or vague. Fuzzy Logic or fuzzy systems are systems to be exactly defined and fuzzy control is a special kind of linear/nonlinear control that would also be precisely defined. A real world is very complex for precise description, therefore, concept of approximation comes ahead and must be introduced so to obtain a reasonable yet a track-able model. As the world is transforming into the information era, human knowledge become ever more significant. A need is felt here to formulate a theory where human knowledge can be interpreted in a systematic manner and put it into engineering systems, together with other information like mathematical model and sensory measurement. Misunderstanding the words in communication or vagueness e.g. Heap of grain, Height of a person from different area like China or Australia, Weather (cold / hot) comparison of Gilgit and Sibi, Young or old

Concept of a set and set theory are very dominant and vital concepts in mathematics. The principal notion of set theory about exclusive belongingness of an element that either it belongs to set or belong, has made it impossible to represent much of human discourse and concepts. For example, how one can represent notions/statements like *large* profit, *high* pressure, *tall* man, *wealthy* woman, *moderate* temperature. Ordinary set-theoretic representations would be requiring the maintenance of a crisp differentiation in a very artificial manner: *high, high to some extent, not quite high, very high.*

2.2.2 History

Fuzzy logic was invented by Prof Lotfy Zadehin1965who wrote that *"imprecisely defined sets or classes play an important role in human thinking, particularly in the domains of pattern recognition, communication of information and abstraction."*

2.2.3 Why to invent and Use Fuzzy Logic

Fuzzy Logic be used because of following: -

- Of its ability to define relationships in less than exact terms
- Of its ease in simulating many real world judgments e.g. linking study with degree of success, following a target
- It copes with non-linearity just as well as with linear relationships
- It can simulate natural language intercourse.

- It is very easy to use and flexible.
- It reduces the design development cycle
- It simplifies design complexity
- Time to market is improved
- It is better alternative solution to non-linear control
- Control performance is improved
- Implementation is simple
- Hardware cost is reduced

2.2.4 Fuzzy Set Theory

Concept of fuzzy logic is started with fuzzy set. A set without crisp or clearly defined boundary is a *fuzzy set*. Only those elements can be part of this set that contain only a partial degree of membership.

Membership function (MF) is a curve defining mapping of every point of the input space to a membership value (or degree of membership) between 0 and 1. The input space is termed as the ***universe of discourse***, a decorative name for a simple concept. Few types of Membership Functions are as follows: -

- **Triangular**

$$f(x;a,b,c)=\begin{cases}0, & x\le a\\ \dfrac{x-a}{b-a}, & a\le x\le b\\ \dfrac{c-x}{c-b}, & b\le x\le c\\ 0, & c\le x\end{cases}$$

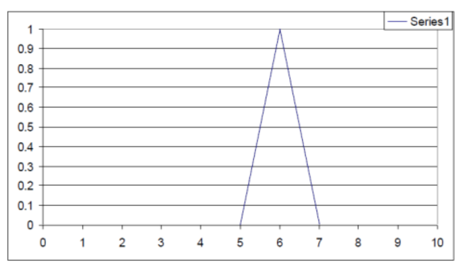


Figure 2.13: Triangular MF Equation and Graphical Representation

- **Trapezoidal**

$$f(x;a,b,c,d)=\begin{cases}0, & x\le a\\ \dfrac{x-a}{b-a}, & a\le x\le b\\ 1, & b\le x\le c\\ \dfrac{d-x}{d-c}, & c\le x\le d\\ 0, & d\le x\end{cases}$$

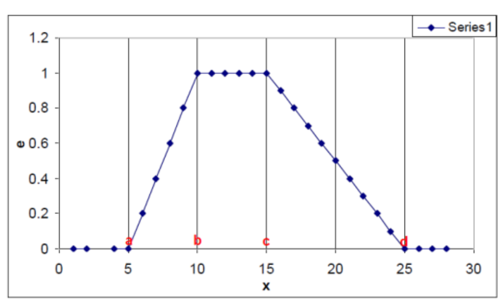


Figure 2.14: Trapezoidal MF Equation and Graphical Representation

- **Generalized Bell Curve**

$$f(x; a, b, c) = \frac{1}{1 + \left|\frac{x - c}{a}\right|^{2b}}$$

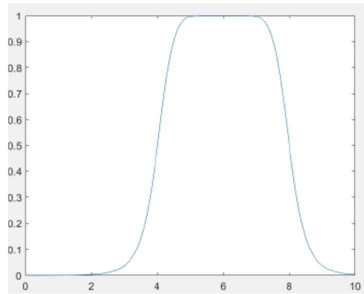


Figure 2.15: Bell Curve Equation and Graphical Representation

- **Gaussian Curve**

$$f(x; \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}}$$

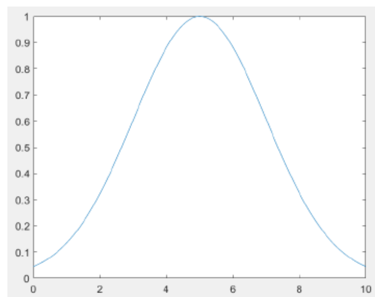


Figure 2.16: Gaussian Curve Equation and Graphical Representation

- **Sigmoidal and Double Sigmoidal Curves**

$$f(x; a, c) = \frac{1}{1 + e^{-a(x-c)}}$$

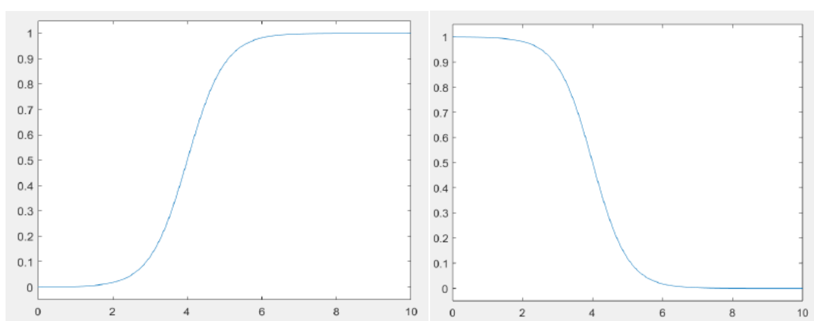


Figure 2.17: Sigmoidal MF Equation and Graphical Representation

2.2.5 Fuzzy Knowledge-Based System

A fuzzy knowledge-based system (KBS) is a system that does approximate reasoning. Typically, knowledge representation and reasoning in Fuzzy knowledge based systems are based upon the application of Fuzzy Set Theory. Facts and rules are main elements of a fuzzy knowledge base. Fuzzy Knowledge-Based System consists of following three elements: -

- **Membership functions**

- **Linguistic variables**. A linguistic variable is a variable that comprises of values that are words or sentences in a natural or artificial language. Fr example, if age is inferred as a linguistic variable, then the term-set, T( ), that is, the set of its linguistic values, may be

  T(age) = young + old + very young + not young + very old + very very young + rather young + more or less young + …….

  where every terms in T(age) is a tag of a fuzzy subset, of a universe of discourse say A=[0,50].

- **If Then Rules – Rule Base.** The fuzzy rules, or the vague rules, can also be termed as linguistic *rules.* These comprises of two parts, first an **antecedent/premise** (the IF part) and the second; a **consequent/conclusion** (the THEN part). The first part is description of an object or event or state in the form of a fuzzy specification of a measured value, whereas the second part describes an appropriate fuzzy value.

In any Fuzzy Knowledge Base System, input is fuzzyfied using fuzzyfier, then directed to Inference engine where rule base is applied to get the results, that are further sent to defuzzyfier for defuzzification.

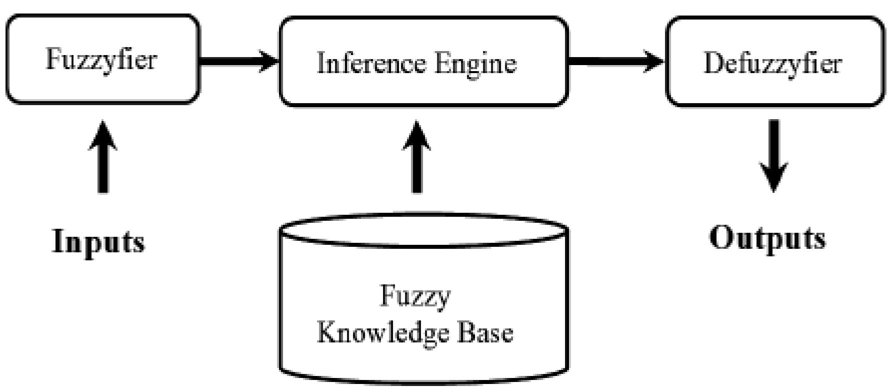


Figure 2.18: Fuzzy Knowledge Based System

CHAPTER – 3

LITERATURE REVIEW

3.1 Automated Glaucoma Detection

While diagnosing retinal ailments where hazard of sight loss has more likelihood, manual conventional procedures like direct and indirect ophthalmoscopy, scanning laser ophthalmoscopy (SLO), Optical Coherence Tomography (OCT) or Fluorescein Angiography, estimation of Intra-Ocular Pressure (IOP) utilizing Gonioscopy, Tonometer, Pachymetry, and many more for investigation and finding have become monotonous and conspicuous. Automated techniques of investigation expect that further patients will be separated and more dependable results can be produced in comparatively reduced time. Therefore, automated or programmed investigation of Glaucoma is taken to be more imperative at the present time.

Numerous computerized detection practices are accessible in which state of art fundus retinal images are used to detect the harm. Optic Nerve Head (ONH) being key characteristics of retina which is affected by glaucoma remains major focus of investigation. Because of this factor, optimum practices follow method of extracting ONH and its adjacent area of interest. Nevertheless, at similar time more important characteristics like RNFL erosion, peripapillary atrophy and vasculature shift remain under observation and procedures have been developed to identify these deviations in order to analyze the ailment. It analyses best accessible automated abstraction of anatomical components from retinal fundus images in order to assist early diagnosis of ailment. Prevailing extraction procedures which depend on elements including Retinal Nerve Fiber Layer (RNFL), Optic Cup to Disk Ratio (CDR), Peripapillary Atrophy (PPA), Vasculature Shift, Neuroretinal Rim Notching, and many more, have been deliberated what leads to extraction of proficient components linked with analysis.

During the research Walter et al [14] shown a methodology in which RGB image was replaced over to Hue-Luminance-Saturation (HLS) space. A thresholding was coupled to restrain Optic Disk focus in luminance channel. Watershed transform is utilized to recommend precise limit of optic disk by employing red channel of the RGB image what comprises morphological preprocessing of gradient image. Once Watershed Transform has done, image is detached into tiny segments known as super pixels. Red plane was selected as Optic Disk boundary is extra conspicuous here. While deciding Optic Disk, Watershed change is obliged by markers got from a previously calculated Optic Disk center.

During research Zhu et al. [15] employed Hough Transform. By using this method on edge map which was attained from using morphological operations on Luminance gray scale of picture. While standardizing every part of RGB space luminance grayscale can be attained. Through said method is roughly related with principal converging of retinal veins. Inventors advised that due to feeble edge data their method dissatisfaction on low quality images as round Hough space may be deluded. Aquino et al. [16] approximated Optic Disk limit using Circular Hough alteration on angle picture got prior to exclusion of veins. This is attained from specialist that their results were contrasted and ’Roundabout Gold Standards’ (benchmarks). In this context, they related that roundabout estimations could beaten by implementation with curved guess and deformable methods.

While carrying out research Babu and Shenbagadevi [17] employed k-means clustering succeeding to shifting over picture into YUV shading space (one luma Y and two chrominance UV segments) in view of Commission Internationale de Éclairage (CIE) format. By computing CDR by taking rectangular zone calculations of both Optic Disk and Optic Cup. In this, general accuracy of approach was enforced by contrasting CDR readings and those got from Gold Standard qualities from specialists.

During conduct of research Daniel Welfer et al [18] depicted a multipurpose morphological method for inbred finding of optic disc in computerized shading eye fundus images. In this technique, he was intended to distinguish optic disc center focus and optic circle rim. In presenting color input retinal image perceptually uniform Luv color space was adopted. A technique which is deliberated in research has capability to notice center of optic disc is precise up to 100 % and 97.75% using DRIVE and DIARETDB1 databases. This technique has capability to correct all optic disc regions which are being spotted and those are within limits of optic disc marked manually. This suggested technique has sensitivity 83.54% and specificity 99.81% for recognizing rim of optic disc which is in DRIVE database, while DIARETDB1 database had specificity 99.76% and sensitivity 92.51%.

Meanwhile in his research, Yuji Hatanaka et al [19] described that existence of glaucoma is often diagnosed through measuring cup-to-disc ratio by ophthalmologists; though, determining cup area on the basis of computational algorithm is a very difficult task. Measurement of cup-to-disc ratio using a vertical profile on the optic disc has been devised and suggested for further wide-ranging and comparatively easily implementable technique. Subsequently, to notice edge of optic disc, Canny edge detection filter was utilized and profile of center of optic disc was attained. Consecutively, with help of categorizing of profiles built on zero-crossing technique, edges of cup area were reported. Vertical cup-to-disc ratio was computed in end. AUC of 0.947 was attained when 45 pictures together with 23 glaucoma pictures were used for evaluation of said technique. Table 3.1 below also presents available techniques for glaucoma detection.

Table 3.1: Literature Review Glaucoma Detection

Ser	**Target Feature**	**Technique Applied**	**Images Tested**	**Obtained Results**	**Pub Year**
1	CDR	Optic Disc and Optic Cup segmentation is done using texture base and model based approach. Template matching and clustering techniques are also used. [20]	50	98% Accuracy	2019
2	Misc features	Features extraction using Median filter, Random transform (RT), Modified census transform and Gabor transform. [21]	35	97% Accuracy 97.8 % Sensitivity 95.8% Specificity	2018
3	Optic Disc & Optic Cup	Region based active contour model for OD and OC segmentation based on structural and gray level properties of cup for measurement of CDR & ISNT rule verification. [22]	59	Average correlation coefficient of 0.916 for OD & 0.835 for OC	2016
4	Misc features	Feature extraction like mean, variance, kurtosis, energy, entropies etc (total 23) using	510	89.75% Sn, 96.2% Sp, 93.1% Acc	2015

		Gabor transform, principal component analysis (PCA) and SVM classifier. [23]			
5	Neuro-retinal rim NRR	Disc damage likelihood scale with features like blood pressure, age and ethnicity. [24]	47	89% Accuracy	2014
6	RNFL	Texture & fractal description followed by classification using support vector machine classifier. [25]	74	0.87 Correlation for severe loss of RNFL	2014
7	Progressive atrophy of RNFL	Features extraction based on Gaussian Markov random fields and local binary patterns, together with various regression models for prediction of the RNFL thickness. [26]	24	Correlation (Normal: 0.72, Glaucomatous: 0.58) between outputs of predicted model & OCT	2014
8	Blood vessel structure	Segmentation of vascular bundle region & measurement of vascular displacement from normal position using chessboard metric. [27]	67	93.02% Sn, 91.66% Sp, 91.34% Acc	2014
9	HOS simulants	Higher order spectra (HOS) cumulants extracted from Radon transform (RT). [28]	272	100% Sn, 92% Sp, 92.5% Acc	2013
10	Optic Disc & Optic Cup	Superpixel classification coupled with center surround statistics. [29]	650	Average overlapping error (OD: 9.5%, OC: 24.1%)	2013

11	CDR	Coarse & accurate localization of optic disc / cup using green band of RGB image [30]	120	92% Success rate	2013
12	HOS and DWT	Automated identification of glaucoma using HOS and discrete wavelet transform features and SVM classifier with kernel function polynomial of order 2. [31]	60	93.3% Sn, 96.6% Sp, 95% Acc	2012
13	CDR / BV area ratio in IS & NT sides	K-means clustering/ local entropy Thresholding. [32]	36	95% Classifica-tion rate	2011

3.22 Use of Fuzzy Logic in Image Processing

Fuzzy logic in comparison to conventional available techniques, is a new language and tool that is now being used in various fields to get better results. Main advantage of fuzzy logic is that it deals vagueness and ambiguity in more efficient way. Few papers/studies related to my work have been studied and brief details are added in table below.

Table 3.2: Literature Review Use of Fuzzy Logic in Image Processing

Ser	**Research Paper**	**Technique Applied**	**Obtained Results**	Pub Year
1	Edge Detection using Fuzzy Logic (Fuzzy sobel, fuzzy tempelate and Fuzzy Inference System)	Fuzzy logic applied augmented with conventional technique. [33]	Edges detected	2018
2	Comprehensive study of Edge Detection for Image Processing Applications	Comparison of various Edge Detection methods was carried out. [34]	Edge detection is application oriented. Canny operator gives better results but with noise	2017

3	Edge Detection method for Image Processing based on Generalized Type 2 Fuzzy system	Type 2 fuzzy system is used. [35]		2014
4	Fuzzy Inference System based Edge Detection Using Membership Functions	Trapezoidal membership functions are used with 3x3 mask scanning. [36]	Comparatively accurate output	2015
5	Image Enhancement using Fuzzy Technique	Different gray level assignment to different regions [37]	Fuzzy method produced efficient results	2014
6	Improved Image Enhancement Algorithm based on Fuzzy Set	Pal algorithm is used for enhancement [38]	Continuous membership functions give better results	2012
7	Fuzzy Logic based Histogram equalization for Image Color Enhancement	Comparison of various histogram equalization techniques HE, BBHE, MMBEBHE, BPDFHE and FHE [39]	Fuzzy produced best results	2013
8	Detection of Edges using Fuzzy Inference System	Fuzzy knowledge base used with 9 inputs and 1 output. Middle of max method is used for Defuzzification [40]	Edges detected but not sharp	2013
9	Improved Image Enhancement Algorithm based on Fuzzy Set	Pal algorithm is used for enhancement [41]	Continuous membership functions give better results	2012

CHAPTER – 4

TECHNIQUE USED FOR GLAUCOMA DETECTION IN BENCHMARK STUDY

4.1 Basic Concept

Automated segmentation of optic disc boundary and diameter calculation using fundus imagery [43] was taken as benchmark study. To detect glaucoma using CDR method, OD and OC segmentation and diameter calculation is required. Automated segmentation of OC remains a challenge due to overlapping of blood vessels (BV), poor color contrast, less prominence due to pathological disorders. Due to these inherent problems of BV occlusion and contrast, instead of using CDR, a parameter of ***Vasculature Alteration*** was adopted for detailed analysis and assessment of glaucoma. Following are the three main steps for glaucoma detection:-

- OD segmentation and reference point detection
- Vasculature displacement measurement
- Biometric approach

4.2 Glaucoma Detection

4.2.1 OD Segmentation and Reference Point Detection

In order to segment out optic disc, RGB image was segregated into red, green and blue planes to assess the prominence of features in different conditions. Optic cup was most prominent in green plane however red plane showed the most encouraging contrast result for optic disc hence selected for further processing and segmentation of this required feature. Obtained red plane of RGB image was converted into grayscale for application of segmentation techniques. Grayscale image further enhanced the feature of optic disc in the image. Input image was divided into four portion each having both background and some part of desired feature need to be extracted. Adaptive thresholding technique was applied in which threshold of all portions were calculated separately using the histogram and on the basis of that value image was converted into binary image from grayscale image. Few resultant images had some artifacts due to poor contrast and low quality of image therefore another technique of connected component analysis was applied on the binary images. All the pixel with value ‘1’ and connected with each other were labelled and grouped together. The size of each segregated component was then calculated and the one having maximum number of pixels with value ‘1’ was declared as the optic disc as no other feature was bigger than this feature while remaining all were considered as the artifact and converted into ‘0’. Final image was acquired after applying morphological operation using disc type structuring element. Parametrization was applied on binary image of segmented OD and an image showing only the boundary of OD is achieved for further assessment

Figure 4.1: OD segmentation result

5.2.2 Vasculature Displacement Measurement

For assessment of glaucoma method of vasculature shift measurement inside optic disc was adopted. Blood vessels in RGB image of ROI was enhanced using wavelet transform and then converted into binary image after undergoing multilayered thresholding technique. Figure 4.2 illustrate the outcome of three main steps involved in extraction of blood vessels.

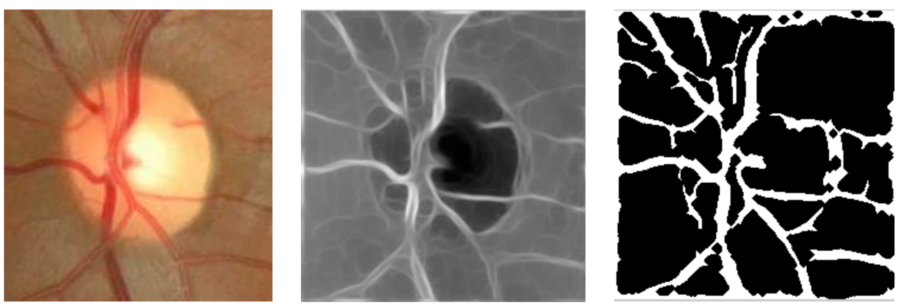


Figure 4.2: Blood vessels extraction using Wavelet Transform

Redundant information contained in extracted image utilizes extra resources and increase computational time hence required to be removed. AND operation between binary images of segmented OD and vascular bundle fulfilled this requirement and the obtained image is demonstrated in figure 4.3.

Figure 4.3: Resultant blood vessels extracted image of OD using AND operation

In order to find out the vasculature shift the extracted blood vessels were distributed into three portions i-e nasal, inferior and superior. Masking was done and then centroid of each portion was assessed separately and then weighted mean was calculated.

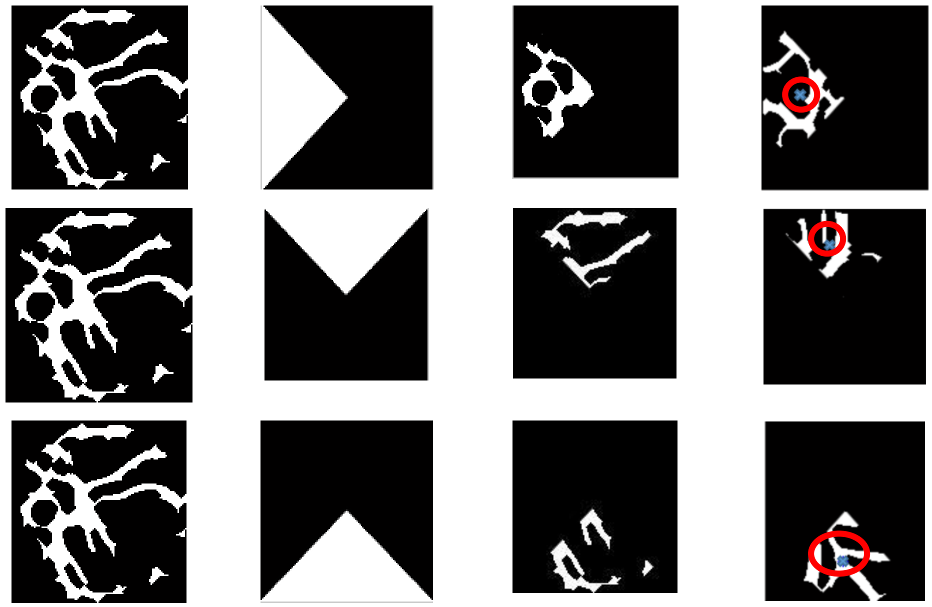


Figure 4.4: Masking and Centroid

4.2.3 Biometric Approach

Large dispersion of BV displacement (Normal images between 67.48 to 71.47 & Glaucoma images between 69.07`to 76.69) with overlapping range of 69.07 to 71 .47 caused too many false results hence reduced system accuracy (approximately 71%). Images lying inside overlapping range were then segregated as suspected glaucoma. Comparison module was designed and these suspected images were passed through another step designed in-line with biometric approach for enhancing accuracy. After applying this approach overall accuracy of 91.34% was achieved.

4.3 Summary and Results

Vasculature displacement is one of the accepted physiological parameters used for diagnosing glaucoma. The accuracy of evaluating correct vascular shift depends upon correct segmentation of optic disc and blood vessels contained inside OD boundary. This study was aimed at automated detection of glaucoma in digital retinal fundus images while employing novel biometric approach. Adaptive thresholding technique augmented with a connected component algorithm and morphological operations was used for OD segmentation. Furthermore, a vector based approach coupled with normalized grayscale image comparison was utilized for automated evaluation of OD radii vector and segregation of glaucomic images from normal ones. An accuracy of 91.34% was achieved.

Table 4.1: Results of Benchmark Study for 26x Fundus Images

Results – Benchmark Study	
Sensitivity	93.02
Specificity	91.66
Accuracy	91.34

CHAPTER – 5

PROPOSED METHOD FOR AUTOMATED GLAUCOMA DETETCTION

5.1 Overview

Cup-to-disc ratio (CDR) & ISNT rule are the most accepted physiological parameters for detecting glaucoma however accuracy depends upon correct segmentation & measurement of Optic Disc (OD) and Optic Cup (OC) in both cases. Automated segmentation of OC remains a challenge due to overlapping of blood vessels (BV), poor color contrast, less prominence due to pathological disorders hence affect accuracy of method. To overcome this problem, fuzzy logic augmented with image processing toolbox, has been used for correct and accurate segmentation of OC and OD both. In propsed method, Glaucoma is being detected using CDR method on Fundus images using Fuzzy Logic. Adopted method is as follows: -

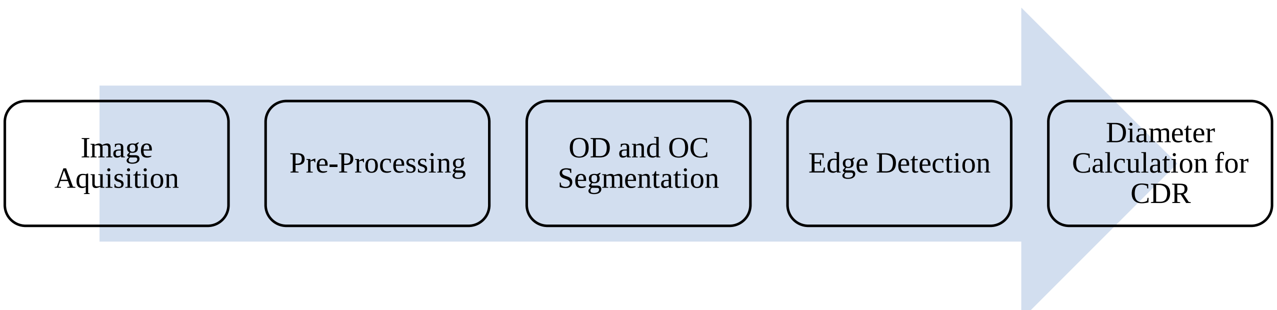


Figure 5.1: Automated Glaucoma Detection Steps

5.2 Data Set Collection – Fundus Images

Data set for this research i.e Fundus images of glaucoma and non-glaucoma patients were selected from Benchmark study as the results of Fuzzy Logic technique and the one followed in benchmark study had to be compared. No dataset of glaucomic patients was available online, so Ibrahim Eye Hospital Gujranwal and Armed Forces Innstitiue of Opthamologoy Rawalpindi were contacted to provide fundus images of Pakistani based ethnic group galucoma patients, that builded up base for benchmark study dataset. In this study, 16x fundus images (8x glaucoma and 8x non-glaucoma) have been taken under consideration.

5.3 Image Acquisiton

A Fundus Camera TRC-NW8F, Non-Mydriatic Retinal Camera (Topcon, Japan) was used for said purpose. This 12.3 megapixel camera provides high resolution images with 45^{O} field of view. Images of eyes of seven female and eight male patients between 38 to 65 years of age were taken. Images were stored in JPEG format and had a resolution of 3216x2136 pixels.

5.4 Image Pre-Processing

While capturing fundus images of patients' eyes, image eminence was affected by various factors like inter technician proficiency, inability of patients to focus on external targets given by the observer, media opacities mainly due to different diseases and large image size. To made the image data more practical to be utilized in subsequent study, pre-processing was required.

5.4.1 Contrast Enhancement

Many fundus images were low in contrast, which resulted poor visibility and merging of ONH with the retinal background. In such conditions it was very difficult for the naked eye to differentiate between different retinal features, hence contrast enhancement has been used to distribute intensity values uniformly over a broad range to enhance image quality.

5.4.2 ROI Extraction

The original image acquired through the fundus camera (size 3216 x 2136) had details of whole retina including macula, fovea, retinal nerve fiber layer and blood vessels. For this research, information other than Optic Disc region was redundant. Area/region of interest i.e Optic Disc occupied approximately 600 x 600 pixels. This region was extracted by picking up all three color channels of the brightest point inside the Optic Cup, by making it midpoint of ROI square. Extracted ROI was covering complete OD region with appropriate clearance from edges. Figure 5.2 depicts the original input fundus image and extracted ROI.

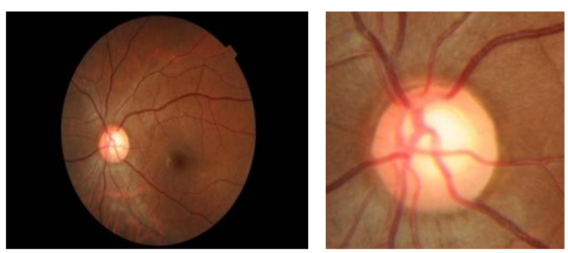


Figure 5.2: Original and ROI Extracted Image

5.5 Optic Disc Feature Segmentation

Optic Disc was segmented from extracted ROI image by using few steps mentioned in figure 5.3.

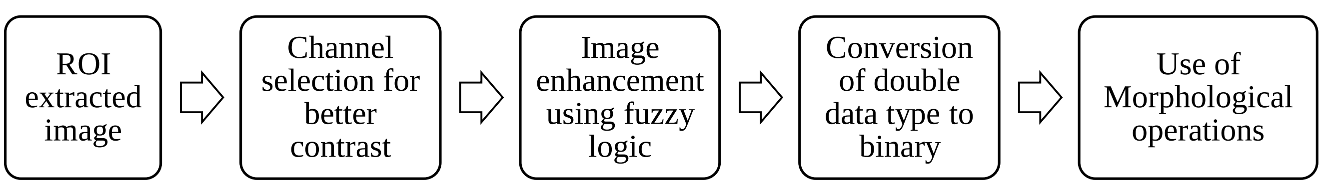


Figure 5.3: Optic Disc Feature Segmentation

5.5.1 Channel Selection for Better Contrast

Extracted ROI is combination of red, green and blue components in its RGB space. Optic Disc had better contrast in the red plane. To get Optic Disc more prominent from rest of the image data, red channel was selected from RGB image, and was further enhanced for better contrast.

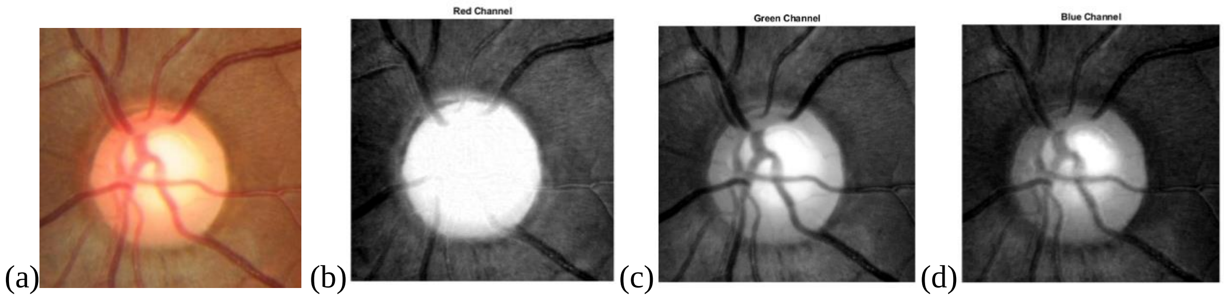


Figure 5.4: (a)Input RGB Image (b)Red Channel (c)Green Channel (d)Blue Channel

5.5.2 Image Enhancement Using Fuzzy Logic

Intensity values of any grayscale image varies between 0 to 255. To segment the optic disc from image, concept of assigning different gray values to disc and background data in image was used. The same was implemented in MATLAB by using a novel technique i.e. Fuzzy Logic, in subject problem area. **Fuzzy logic implementation** required following three parameters: -

- **Defining inputs and outputs.** Image pixel values i.e. intensity levels in grayscale image were used as input and output parameters. One input and one output was defined. Original intensity value of any pixel in grayscale image was taken as input and desired gray level intensity value at the same pixel was the output. In disc segmentation case, desired output image was only one circle having some different intensity from rest of the image. For getting desired results, intensity range of background data in input image which was spanning from 0 to 150, was compressed to darker side i.e. 0 to 10, and for disc feature intensity range was compressed to brighter side i.e. 244 to 255, as shown in figure 5.5.
- **Membership functions for inputs and outputs.** Triangular membership functions described by equation (1), were used for both the input and output. Parameter a, b, c, d in defining membership functions were selected in accordance to image gray levels.

$$f(x;a,b,c)=\begin{Bmatrix} 0, & x\le a \\ \frac{x-a}{b-a}, & a\le x\le b \\ \frac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{Bmatrix} \quad (1)$$

- **Rules.** Following two rules were used to get the desired output: -
  - **Rule 1**: If original pixel value is dark (0 to 150), then enhanced pixel value is darker (0 to 10)
  - **Rule 2**: If original pixel value is bright (150 to 255), then enhanced pixel value is brighter (245 to 255)

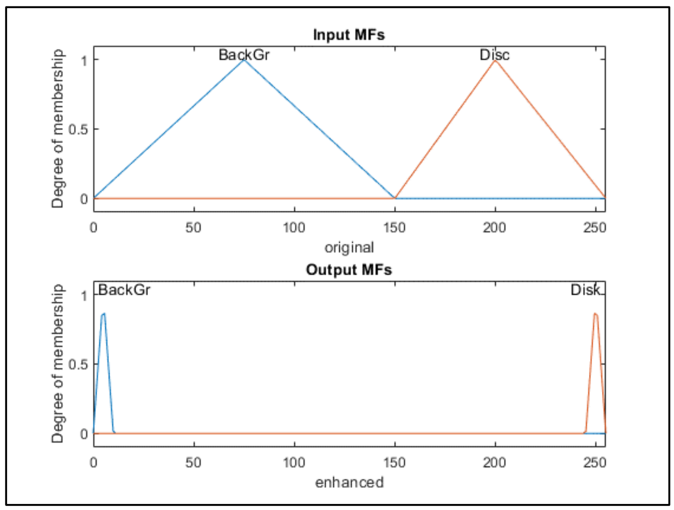


Figure 5.5: Fuzzy Logic Membership Functions defining Inputs and Outputs of Original and Enhanced Image for OD Segmentation

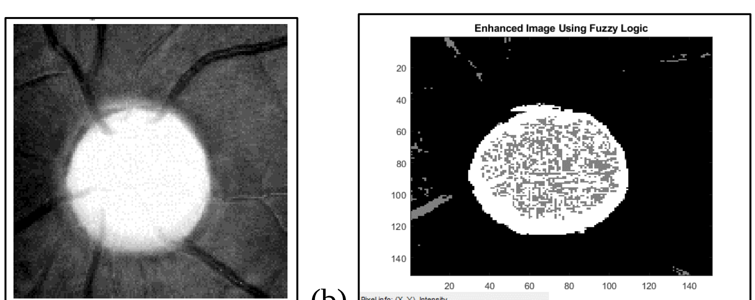
(a)  (b)

Figure 5.6: (a) Input image to fuzzy logic rules (b) Output image

5.5.3 Conversion of Double Data Type to Binary

Fuzzy logic deals with double data type. Before applying above defined fuzzy rules over input grayscale image, it was first converted to double data type using MATLAB built-in command double. Output of fuzzy logic, shown in figure 5.7(b) above, was with some offset and disturbed scaling. Before using this output for further processing, it was converted to binary logic i.e. 0s and 1s. White portion representing disc feature was assigned binary value 1 and background data was assigned binary value 0.

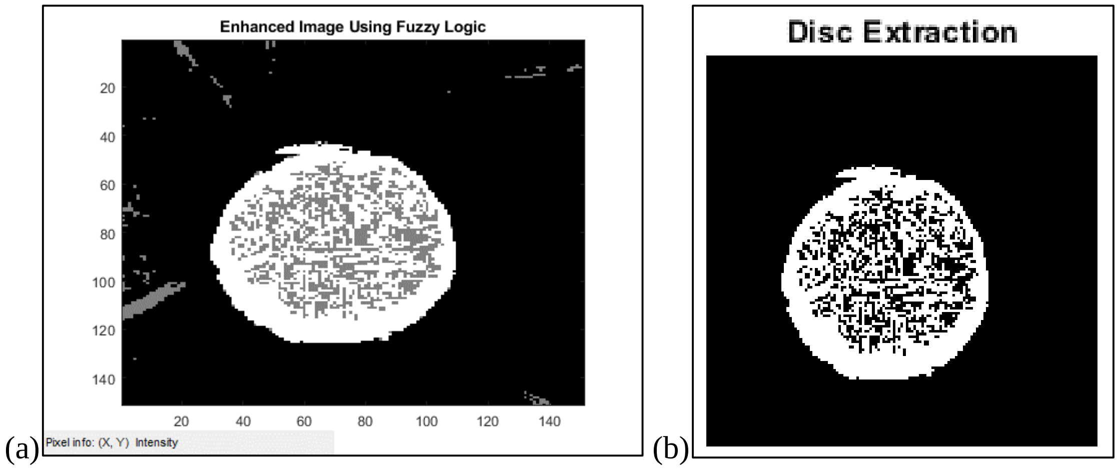


Figure 5.7: (a)Fuzzy Logic Double Data Type Output (b)Converted Binary Output

5.5.4 Use of Morphological Operations

Morphological operations (imfill, medfilt2, erosion, dilation, opening and closing) were used to remove minor artifacts / unwanted components present inside extracted disc feature and to smooth out the boundary of optic disc.

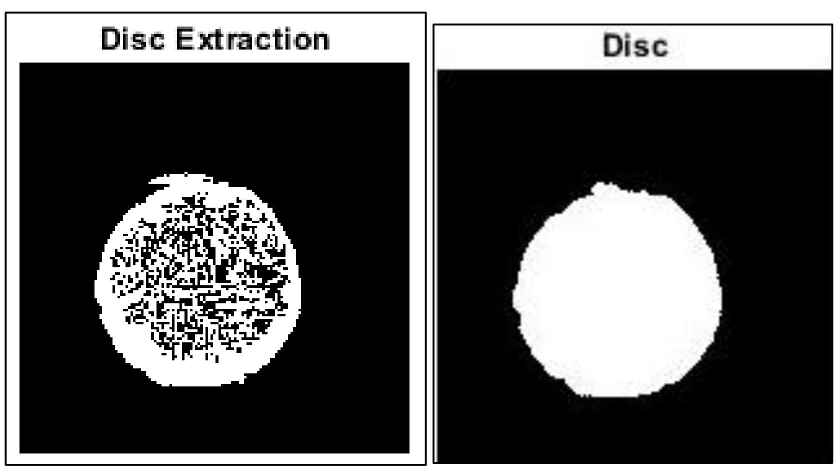


Figure 5.8: Morphological Operations Results

5.6 Optic Cup Feature Segmentation

Automated segmentation of Optic Cup always remained a challenging task due to overlapping blood vessels, poor color contrast etc. In this study, fuzzy logic has been used to overcome and address all these inherent issues, as it deals with the vagueness in more efficient manner. Cup segmentation was done exactly on the same lines as Optic Disc has been segmented out, as explained above.

5.6.1 Channel Selection for Better Contrast

Extracted ROI input image had three color channels in its RGB space. Optic Cup had better contrast in green channel. Therefore, green channel was selected and enhanced to get the desired results.

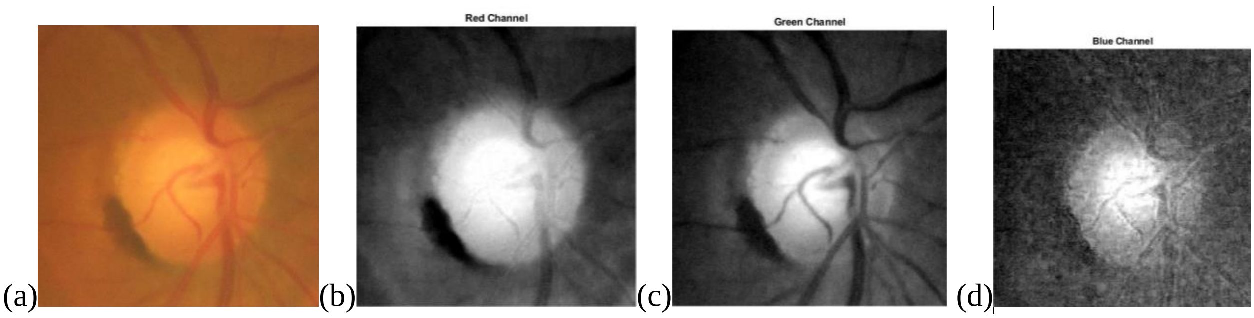


Figure 5.9: Optic Cup Contrast in RGB Space

5.6.2 Image Enhancement Using Fuzzy Logic

Optic Cup was extracted using fuzzy logic. Details of fuzzy inference system defined and results after its implementation in MATLAB is as follows: -

- **Inputs and Outputs**. Image pixel values were taken as input and outputs. 1x input (original gray value) and 1x output (enhanced gray value) was defined.
- **Membership Functions**. Triangular membership functions as described in equation (1) above, were used for both inputs and outputs.
- **Rules**. Following two rules were implemented in MATLAB.
    - **Rule 1**: If original pixel value is dark (0 to 150), then enhanced pixel value is darker (0 to 10)
    - **Rule 2**: If original pixel value is bright (190 to 255), then enhanced pixel value is brighter (245 to 255)

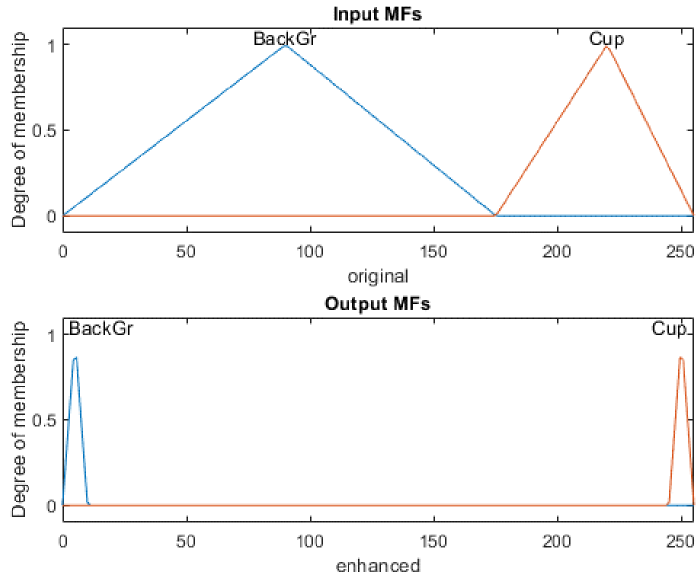
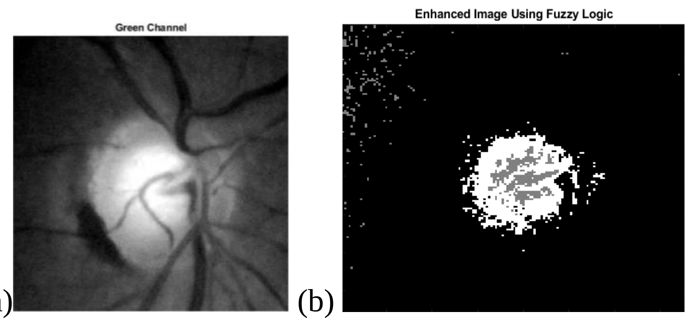


Figure 5.10: Fuzzy Logic Membership Functions defining Inputs and Outputs of Original and Enhanced Image for OC Segmentation

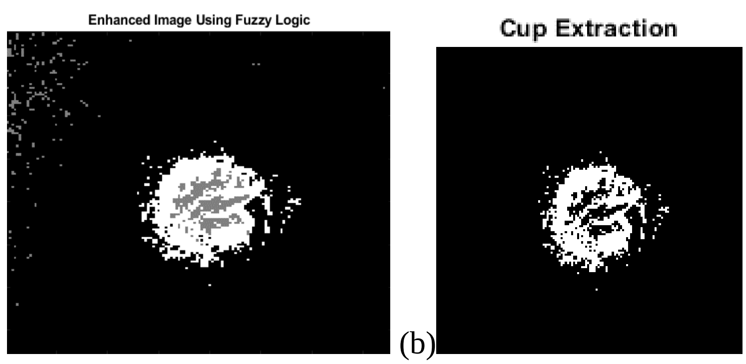


(a) (b)

Figure 5.11: Input and Output of Fuzzy Rules for OC Segmentation

5.6.3 Conversion of Double Data Type to Binary

Offset and disturbed scaled double data type output of fuzzy rules was then converted to binary logic. Results are as shown in Figure 5.12.



(a) (b)

Figure 5.12: Conversion of Double Data Type to Binary

5.6.4 Use of Morphological operations

Morphological operations (imfill, medfilt2, erosion and dilation, opening and closing) were used to remove unwanted minor artifacts and to smooth the optic cup boundary for better visualization of cup.

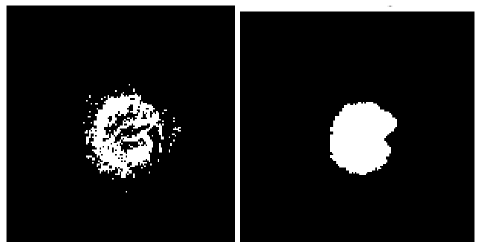


Figure 5.13: Extracted Cup Feature

5.7 Edge Detection

Edge detection is an image processing technique for finding the boundaries of objects within images. Many conventional techniques like Sobel, Canny, Prewitt, Roberts, MATLAB built-in command "bwperim", for said purpose are available but in this study fuzzy logic was used to detect edges of optic disc and optic cup. Two different approaches of fuzzy logic were introduced i.e. Pixel to pixel operation method and Gradients method.

5.7.1 Pixel to Pixel Operation Method

In this method, intensity differences of pixels were calculated, and were further used in few fuzzy rules defined below, to detect edges of image. Let's suppose an image has n number of pixels. Intensity value of every pixel is represented by 'zi'. A 3x3 kernel was selected and intensity differences 'di' for all pixels of image were calculated using formula di=zi-z5, shown in figure below. The kernel was moved with step of 1, over complete image having i number of rows and j number of columns.

z1	z2	z3
z4	z5	z6
z7	z8	z9

d1	***d2***	d3
d4	d5	***d6***
d7	***d8***	d9

Figure 5.14: (a)Pixel values/intensity neighborhood (b)Intensity Differences

Out of 9x intensity differences calculated above in single step, 4x intensity differences i.e. d2, d4, d6 and d8 were used in following fuzzy rules to detect edges of image.

- Rule 1 = ‘If d2 is *zero* AND d6 is *zero* then z5 is white’
- Rule 2 = ‘If d6 is *zero* AND d8 is *zero* then z5 is white’
- Rule 3 = ‘If d8 is *zero* AND d4 is *zero* then z5 is white’
- Rule 4 = 'If d4 is *zero* AND d2 is *zero* then z5 is white’
- Rule 5 = ‘else z5 is black’

In above rules, ‘*zero*’ is the input Gaussian membership function, defined by equation (2). ‘*White*’ and ‘*black*’ are two output triangular membership functions, defined by same equation (1) above and *z5* is the edge pixel. Rules were implemented in MATLAB as shown in figure below.

$$f(x;\sigma,c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \qquad (2)$$

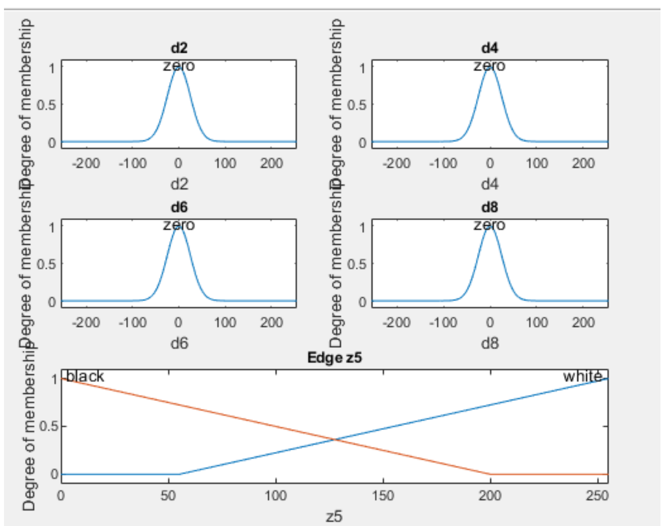


Figure 5.15: Fuzzy Rules implemented in MATLAB – Pixel to Pixel Operation Method

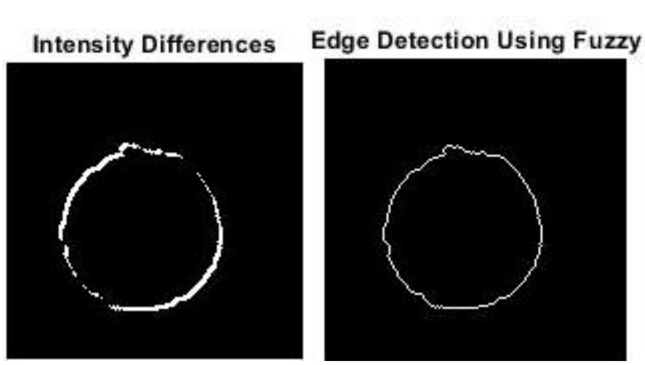


Figure 5.16: Results of Intensity Differences and Edges of Disc

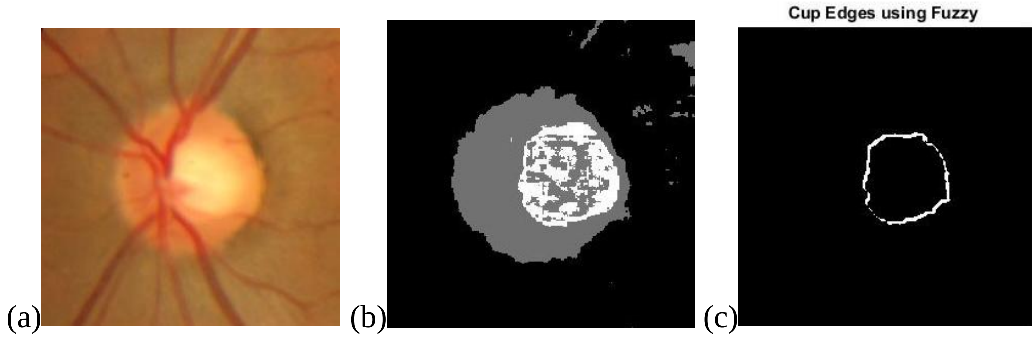


Figure 5.17: Edge Detection of Optic Cup Using Fuzzy Logic (a)Input RGB Image (b)Enhanced Image Output of Fuzzy Rules (c) Edges of Optic Cup

5.7.2 Gradients method

In this method, to detect the edges, X & Y gradients of input image i.e Ix and Iy were taken as input to the fuzzy system. These gradients were then used in two following fuzzy rules:-

- Rule 1 = 'If Ix is zero and Iy is zero then Iout is white'
- Rule 2 = 'If Ix is not zero or Iy is not zero then Iout is black'

In above rules, *zero* is the same input Gaussian membership function, whereas *white* and *black* are two output triangular membership functions.

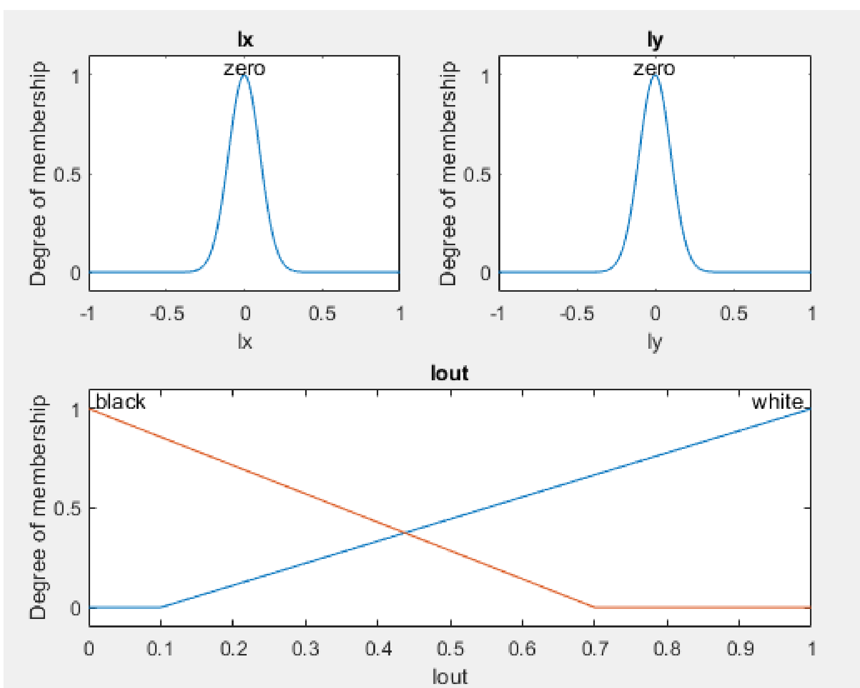


Figure 5.18: Rule Base of Gradients Method for Edge Detection

5.8 Diameter Calculation

Diameter of OD and OC was measured using vector based approach. Vectors of length equal to 1.6 times the horizontal radius of OD were drawn at an interval of 10^o starting from 0^o, along complete circumference of the disc and cup. Euclidean distance between center point of optic disc/optic cup and intersection point of drawn vector with edges of OD/OC was measured.

$$Euclidean\ Distance = d = \sqrt{\sum_{i=1}^{N}(xi - yi)^2} \quad (3)$$

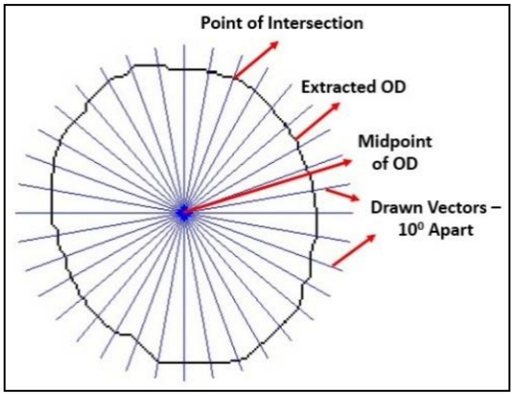


Figure 5.19: Vector Based Approach for Diameter Calculation

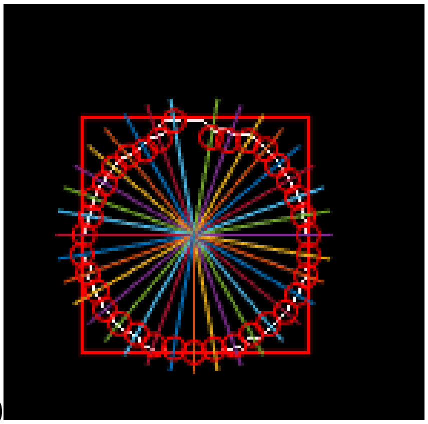
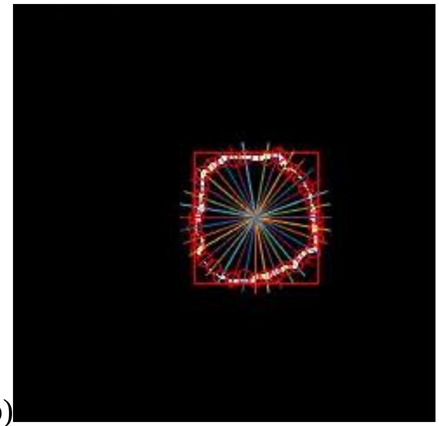
(a)  (b) 

Figure 5.20: (a)Diameter calculation of OD (b)Diameter calculation of OC in MATLAB

CHAPTER – 6

RESULTS AND ANALYSIS

6.1 Experimental Results of Proposed Method

Developed algorithm and code for automated glaucoma detection using CDR method on fundus images using fuzzy logic was validated by running it over multiple fundus images of both normal and glaucoma eyes. To verify the results and accuracy of proposed method, an Ophthalmologist was contacted for providing CDR values of selected dataset as a reference and results of proposed method were compared. Table 6.1 below shows the comparison of ophthalmologist assessment and the results produced by technique followed in this study. Out of 16x fundus images, ophthalmologist classified 8x images whose CDR values ranged from 0.5 to 1, as glaucoma patients and 8x non glaucoma; CDR values ranging from 0.1 to 0.5. Whereas, proposed method diagnosed 9x glaucoma patients and 7x non-glaucoma. 1x fundus image of non-glaucoma patient (ser 8 of table 6.1) was incorrectly marked as glaucoma patient by calculating CDR value 0.52, by proposed technique. Experimental results are tabulated below.

Table 6.1: Comparison of CDR values - Ophthalmic and Proposed Method

Ser	Image	Ophthalmic Results		Proposed Method Results			
		CDR Range	Glaucoma (Yes/No)	Disc Diameter	Cup Diameter	CDR	Glaucoma Detected
1	R1	0.35 – 0.45	No	308.70	112.92	0.37	No
2	R2	0.95 – 1	Yes	263.52	236.48	0.90	Yes
3	R3	0.6 – 0.65	Yes	351.50	216.26	0.62	Yes
4	R4	0.6 – 0.65	Yes	348.36	209.08	0.60	Yes
5	R5	0.6 – 0.65	Yes	323.85	195.78	0.60	Yes
6	R6	0.55 – 0.6	Yes	315.31	178.87	0.57	Yes
7	R7	0.25 – 0.3	No	269.28	81.39	0.30	No
8	R8	0.5	No	380.75	199.84	0.52	Yes
9	R9	0.6	Yes	309.30	190.50	0.62	Yes
10	R10	0.85	Yes	290.18	195.96	0.68	Yes
11	R11	0.65	Yes	135.99	88.05	0.64	Yes
12	R12	0.4-0.45	No	141.08	63.4	0.44	No

13	R13	0.4-0.45	No	126.88	55.3	0.43	No
14	R14	0.4-0.45	No	123.18	51.8	0.42	No
15	R15	0.4	No	133.5	53.3	0.39	No
16	R16	0.45 – 0.5	No	134.64	68.4	0.50	No

6.2 Confusion Matrix

Confusion matrix has been made (table 6.2) to show the efficacy of proposed method. Sensitivity, specificity and accuracy is calculated for attained number of true positive, true negative, false positive and false negative of proposed method (table 6.3), using following equations.

$$Sensitivity = \frac{True\ Positive}{True\ Positive + False\ Negative} \quad (1)$$

$$Specificity = \frac{True\ Negative}{True\ Negative + False\ Positive} \quad (2)$$

$$Accuracy = \frac{True\ Positive + True\ Negative}{True\ Positive + False\ Negative + True\ Negative + False\ Positive} \quad (3)$$

Tables 6.2: Confusion Matrix for 16x Fundus Images

Confusion Matrix		**Proposed Method Results**	
		Glaucoma	**Non-Glaucoma**
Ophthalmic Results	**Glaucoma**	8	0
	Non-Glaucoma	1	7

Table 6.3: Results of Proposed Method for 16x Fundus Images

Ser	**Parameter**	**Proposed Method Results**
1	TP	8
2	TN	7
3	FP	1
4	FN	0
5	Sensitivity	100

6	Specificity	87.5
7	Accuracy	93.75

6.3 Comparison of Benchmark Study and Proposed Method for OD Segmentation

In benchmark study, glaucoma was detected by optic disc segmentation and then by calculating vasculature displacement of displaced blood vessels inside ONH of patients. Whereas in this study CDR method was used for glaucoma detection. The only common part of two studies is optic disc segmentation but with different technique and then its diameter calculation. In benchmark study, optic disc was segmented using basic image processing tools i.e. conversion to grayscale and then binary by adaptive thresholding, connected component analysis, morphological operations, whereas in proposed method fuzzy logic has been used for same purpose that not only reduced number of operations but also given better results as depicted below. Comparison of results of disc segmentation done by both techniques is shown below in figure 6.1 and figure 6.2.

Figure 6.1: OD Segmentation – Benchmark Study Results

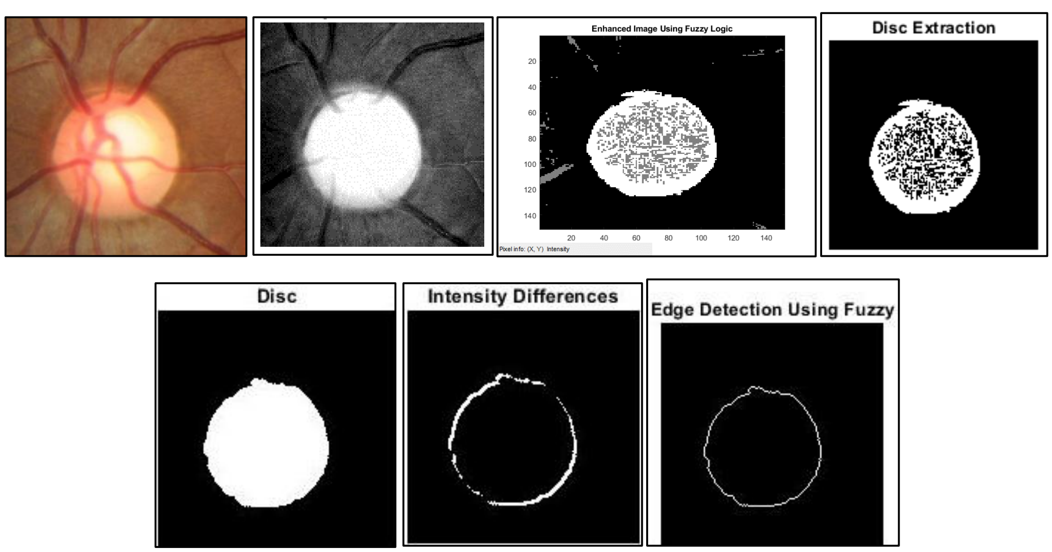


Figure 6.2: OD Segmentation – Proposed Method Results

Diameter for every segmented out optic disc was measured using MATLAB. An accuracy for every image was calculated separately, using Ophthalmic reading as a reference. Comparison of calculated diameter values and accuracy for each image, are shown in table 6.4 below. Third left column of below table has diameter values that were given by classified Ophthalmologist and were taken as reference by both; benchmark study and in this proposed method. It can be seen from all numeric values that for every fundus image, fuzzy logic has given better results that are more close to reference values. Benchmark study gave an avg accuracy of 97.32% for OD diameter, whereas proposed method's avg accuracy is 99.03%.

Table 6.4: Comparison of Benchmark Study and Proposed Method Optic Disc Diameter Results

Ser	**Image**	**Disc Diameter Results**				
		Ref – Ophthalmic Calculation	**Benchmark Study**		**Proposed Method**	
			Diameter	**Accuracy**	**Diameter**	**Accuracy**
1	R1	266	225.2	84.67	263.52	99.07
2	R2	308.5	307.7	99.75	308.70	99.94
3	R3	354	346.3	97.83	351.50	99.29
4	R4	348.5	369.5	93.99	348.36	99.96
5	R5	325	323.1	99.41	323.85	99.65
6	R6	327	309.0	94.51	315.31	96.43
7	R7	271	269.6	99.47	269.28	99.37
8	R8	381	392.5	96.97	380.75	99.93
9	R9	313.5	320.2	97.85	309.30	98.66
10	R10	296	281.2	95.00	290.18	98.03
Avg Accuracy				97.32%		99.03%

6.3 Comparison of Benchmark Study and Proposed Method for Automated Glaucoma Detection

Along with the Optic Disc segmentation and diameter calculation, automated glaucoma detection requires measurement of some other parameters like Optic Cup diameter calculation for computing CDR values or measurement of blood vessels displacement and many other parameters. In benchmark study, along with optic disc measurement, blood vessels displacement was also calculated and on the basis of combined results, glaucoma and non-glaucoma images were segregated, whereas in this study CDR value has been calculated. Overall results i.e. sensitivity, specificity and accuracy of both the techniques have been compared in table 6.5 below. Proposed study which incorporates use of fuzzy logic has given better results with an accuracy of 93.75%. All the fundus images of glaucoma patients were marked as glaucoma by this proposed method thus giving 100% sensitivity. Only 1x non-glaucoma patient was declared as glaucoma.

Table 6.5: Comparison of Overall Glaucoma Detection Results

Ser	**Parameter**	**Benchmark Study**	**Proposed Method**
1	Sensitivity	93.02	100
2	Specificity	91.66	87.5
3	Accuracy	91.34	93.75

CHAPTER – 7

CONCLUSION

7.1 Conclusion

Automated detection of glaucoma using CDR method on fundus images using fuzzy logic is proposed in this study. Dataset of locally available Pakistani based ethnic group is used for validation of suggested algorithm and obtaining results. Proposed method is divided into four main parts i.e. optic disc segmentation, optic cup segmentation, edge detection of optic disc and optic cup and diameter calculation of extracted disc and cup. Novel technique of fuzzy logic is used in segmentation of optic disc and optic cup, first by assigning different gray levels to disc and cup region of ONH in fundus image, and then by calculating intensity differences for further detection of disc and cup edges. Vector based approach is used for diameter calculation of both the optic disc and optic cup, which was used for determining CDR value. Use of Fuzzy Logic has given more accurate results in comparison to use of conventional region segmentation techniques.

Appendix A

MATLAB CODE

AUTOMATED GLAUCOMA DETECTION USING FUZZY LOGIC

Disc Segmentation

```
clear all
close all
clc
 a = imread('r9.jpg');
gray=rgb2gray(a);
r=a(:,:,1);      % Red channel selection for better contrast of Optic Disc
re=imadjust(r);
figure, imshow(re), title('Red Channel'); impixelinfo
g=a(:,:,2);
ge=imadjust(g);
figure, imshow(ge), title('Green Channel'); impixelinfo
b=a(:,:,3);
be=imadjust(b);
figure, imshow(be), title('Blue Channel'); impixelinfo
```

Creating Fuzzy Inference System for Disc feature segmentation

```
I = double(re); % Conversion to double data type as Fuzzy logic deals with double
% creating Fuzzy Inference Sys for Image Enhancement (Disc feature segmentation)
fisIE = newfis('Image Enhancement.fis');
% defining fuzzy input and output
fisIE = addvar(fisIE,'input','original',[0 255]);
fisIE = addvar(fisIE,'output','enhanced',[0 255]);
% adding membership functions for input and output
fisIE = addmf(fisIE,'input',1,'BackGr','trimf',[0 75 150]);
fisIE = addmf(fisIE,'input',1,'Disc','trimf',[150 200 255]);
fisIE = addmf(fisIE,'output',1,'BackGr','trimf',[0 5 10]);
```

```
fisIE = addmf(fisIE,'output',1,'Disc','trimf',[245 250 255]);
figure
subplot(2,1,1), plotmf(fisIE,'input',1), title('Input MFs')
subplot(2,1,2), plotmf(fisIE,'output',1), title('Output MFs')
% defining fuzzy rules
r1 = 'If original is BackGr then enhanced is BackGr';
r2 = 'If original is Disc then enhanced is Disc';
r = char(r1,r2);
% Evaluating created Fuzzy Inference System
fisIE = parsrule(fisIE,r);
I_enhanced = zeros(size(I));
[he wi] = size(I);
for i = 1:he
   for j = 1:wi
        I_enhanced(i,j) = evalfis(I(i,j),fisIE);
   end
end
figure
image(I_enhanced,'CDataMapping','scaled'), impixelinfo
colormap('gray')
title('Enhanced Image Using Fuzzy Logic')
% Conversion of double data type to binary
[s t]=size(I_enhanced);
for i=1:s
   for j=1:t
      if I_enhanced(i,j)>=248;
         I_enhanced(i,j)=1;
      else
         I_enhanced(i,j)=0;
      end
   end
```

```
end

figure
imshow(I_enhanced), impixelinfo
title('Disc Extraction')
 % Morphological Operations for smoothing out Optic Disc
disc=imfill(I_enhanced);
figure
imshow(disc), impixelinfo
title('Filled Disc')
 se=strel('disk',2);
dd=imerode(disc,se);
figure, imshow(dd), impixelinfo
Segmented_Disc=imdilate(dd,se);
figure, imshow(Segmented_Disc), title('Disc'), impixelinfo
```

Edge Detection of Optic Disc Using Fuzzy Logic - Pixel to Pixel Operation Method

```
I_in=double(Segmented_Disc); % Converted to double data type for intensity difference calculation using Fuzzy Logic
 %calculating intensity differences di
[ac_x,ac_y]=size(I_in);
imgg=zeros(size(I_in));
kernel=3;
x=ac_x-kernel;
y=ac_y-kernel;
for i=1:1:x % this loop will monitor the rows
   for j=1:1:y % this loop will iterate through the columns as kernel moves through
      for k=i:kernel+i
          for l=j:kernel+j
             I_diff_1(i,j)=abs(I_in(k,l)-I_in(i+1,j+1));
           end
      end
```

```
    end
end
I_diff;
figure,
imshow(I_diff), title('Intensity Differences'), impixelinfo
 %creating Fuzzy Inference System for Edge Detection
fisEdge = newfis('Edge_Detection.fis');
% adding Fuzzy variables
fisEdge = addvar(fisEdge,'input','d2',[-255 255]);
fisEdge = addvar(fisEdge,'input','d4',[-255 255]);
fisEdge = addvar(fisEdge,'input','d6',[-255 255]);
fisEdge = addvar(fisEdge,'input','d8',[-255 255]);
fisEdge = addvar(fisEdge,'output','z5',[0 255]);
%adding Membership Functions
    %inputs
fisEdge = addmf(fisEdge,'input',1,'zero','gaussmf',[25 0]);
fisEdge = addmf(fisEdge,'input',2,'zero','gaussmf',[25 0]);
fisEdge = addmf(fisEdge,'input',3,'zero','gaussmf',[25 0]);
fisEdge = addmf(fisEdge,'input',4,'zero','gaussmf',[25 0]);
    %outputs
fisEdge = addmf(fisEdge,'output',1,'white','trimf',[55 255 455]);
fisEdge = addmf(fisEdge,'output',1,'black','trimf',[0 0 200]);
figure
subplot(3,2,1), plotmf(fisEdge,'input',1), title('d2')
subplot(3,2,2), plotmf(fisEdge,'input',2), title('d4')
subplot(3,2,3), plotmf(fisEdge,'input',3), title('d6')
subplot(3,2,4), plotmf(fisEdge,'input',4), title('d8')
subplot(3,2,[5 6]), plotmf(fisEdge,'output',1), title('Edge z5')
b=double(I); %fuzzy deals with double
I_edges = ones(size(b));
size(I_edges)
```

```
% picking up four neighbors and applying rules
for i=1:1:x % this loop will monitor the rows
    for j=1:1:y % this loop will iterate through the coloums as kernel moves through
        %top center
        d2= b(i,j+1);
        %left mid
        d4= b(i+1,j);
        % right mid
        d6= b(i+1,j+2);
        %bottom center
        d8= b(i+2,j+1);
        %centre z5
        z5= b(i+1,j+1);
          %defining rules
        r1 = 'If d2 is zero AND d6 is zero then z5 is white';
        r2 = 'If d6 is zero AND d8 is zero then z5 is white';
        r3 = 'If d8 is zero AND d4 is zero then z5 is white';
        r4 = 'If d4 is zero AND d2 is zero then z5 is white';
        r5 = 'If d2 is not zero AND d6 is not zero then z5 is black';
        r6 = 'If d6 is not zero AND d8 is not zero then z5 is black';
        r7 = 'If d8 is not zero AND d4 is not zero then z5 is black';
        r8 = 'If d4 is not zero AND d2 is not zero then z5 is black';
        r = char(r1,r2,r3,r4,r5,r6,r7,r8);
        fisEdge = parsrule(fisEdge,r);
        %applying fisEdge
        I_edges(i,j) = evalfis(b(i,j),fisEdge);
            end
end
figure, image(I_edges,'CDataMapping','scaled'); impixelinfo
colormap('gray')
title('Edge Detection Using Fuzzy Logic - Pixel to Pixel Op')
```

Edge Detection of Optic Disc / Cup Using Fuzzy Logic – Gradient Method

```
Irgb = imread('circle.png');
Igray = rgb2gray(Irgb);
figure
image(Igray,'CDataMapping','scaled')
colormap('gray')
title('Input Image in Grayscale')
I = im2double(Igray);
Gx = [-1 1];
Gy = Gx';
Ix = conv2(I,Gx,'same');
Iy = conv2(I,Gy,'same');
figure
image(Ix,'CDataMapping','scaled')
colormap('gray')
title('Ix')
figure
image(Iy,'CDataMapping','scaled')
colormap('gray')
title('Iy')
edgeFIS = newfis('EdgeDetection');
edgeFIS = addvar(edgeFIS,'input','Ix',[-1 1]);
edgeFIS = addvar(edgeFIS,'input','Iy',[-1 1]);
sx = 0.1;
sy = 0.1;
edgeFIS = addmf(edgeFIS,'input',1,'zero','gaussmf',[sx 0]);
edgeFIS = addmf(edgeFIS,'input',2,'zero','gaussmf',[sy 0]);
edgeFIS = addvar(edgeFIS,'output','Iout',[0 1]);
wa = 0.1;
wb = 1;
wc = 1;
```

```
ba = 0;
bb = 0;
bc = 0.7;
edgeFIS = addmf(edgeFIS,'output',1,'white','trimf',[wa wb wc]);
edgeFIS = addmf(edgeFIS,'output',1,'black','trimf',[ba bb bc]);
figure
subplot(2,2,1)
plotmf(edgeFIS,'input',1)
title('Ix')
subplot(2,2,2)
plotmf(edgeFIS,'input',2)
title('Iy')
subplot(2,2,[3 4])
plotmf(edgeFIS,'output',1)
title('Iout')
r1 = 'If Ix is zero and Iy is zero then Iout is white';
r2 = 'If Ix is not zero or Iy is not zero then Iout is black';
r = char(r1,r2);
edgeFIS = parsrule(edgeFIS,r);
Ieval = ones(size(I));
for ii = 1:size(I,1)
   Ieval(ii,:) = evalfis([(Ix(ii,:));(Iy(ii,:))]',edgeFIS);
end
figure
image(I,'CDataMapping','scaled')
colormap('gray')
title('Original Grayscale Image')
figure
image(Ieval,'CDataMapping','scaled'), impixelinfo
colormap('gray')
title('Edge Detection Using Fuzzy Logic - Gradient Method')
```

```
 [s t]=size(Ieval);
for i=1:s
   for j=1:t
      if Ieval(i,j)>=0.7;
         Ieval(i,j)=1;
      else
         Ieval(i,j)=0;
      end
   end
end
I_edges=imcomplement(Ieval);
figure
imshow(I_edges),impixelinfo
title('Edge Detection Using Fuzzy Logic - Gradient Method')
```

Diameter Calculation of Optic Disc and Optic Cup – Euclidean Method

```
% Diameter calculation
[x,y]=find(I_edges);
xmin=min(x);
xmax=max(x);
ymin=min(y);
ymax=max(y);
x1=xmax-xmin;
y1=ymax-ymin;
midpt_x1=floor((x1/2)+xmin);
midpt_y1=floor((y1/2)+ymin);
figure
imshow(I_edges);
grid on
impixelinfo
hold on
rectangle('Position',[ymin, xmin, y1, x1],'Linewidth',1, 'EdgeColor', 'r')
```

```
plot(midpt_y1,midpt_x1,'Marker','+')
r=0.6*((x1+y1)/2);
theta_degree=0:10:350;
theta_radian=theta_degree*(0.005555*pi);
[x2 y2]=pol2cart(theta_radian,r);
x3=x2+midpt_x1;
y3=y2+midpt_y1;

for i=1:1:10
  plot([midpt_y1,y3(i)],[midpt_x1,x3(i)])
  a=[midpt_x1 x3(i)];
  b=[midpt_y1 y3(i)];
  [xi yi]=polyxpoly(y,x,b,a);
  c1=max(xi);
  d1=max(yi);
  mapshow(c1,d1,'DisplayType','point','Marker','o')
  r1(i)=sqrt((midpt_x1-d1)^2 + (midpt_y1-c1)^2);
end
r1;
avg_r1=sum(r1)/10;

for i=11:1:18
  plot([midpt_y1,y3(i)],[midpt_x1,x3(i)])
  a=[midpt_x1 x3(i)];
  b=[midpt_y1 y3(i)];
  [xi yi]=polyxpoly(y,x,b,a);
  c2=max(xi);
  d2=min(yi);
  mapshow(c2,d2,'DisplayType','point','Marker','o')
  r2(i)=sqrt((midpt_x1-d2)^2 + (midpt_y1-c2)^2);
end
```

```
r2;
avg_r2=sum(r2)/8;

for i=20:1:28
   plot([midpt_y1,y3(i)],[midpt_x1,x3(i)])
   a=[midpt_x1 x3(i)];
   b=[midpt_y1 y3(i)];
   [xi yi]=polyxpoly(y,x,b,a);
   c3=min(xi);
   d3=min(yi);
   mapshow(c3,d3,'DisplayType','point','Marker','o')
   r3(i)=sqrt((midpt_x1-d3)^2 + (midpt_y1-c3)^2);
end
r3;
avg_r3=sum(r3)/9;

for i=29:1:36
   plot([midpt_y1,y3(i)],[midpt_x1,x3(i)])
   a=[midpt_x1 x3(i)];
   b=[midpt_y1 y3(i)];
   [xi yi]=polyxpoly(y,x,b,a);
   c4=min(xi);
   d4=max(yi);
   mapshow(c4,d4,'DisplayType','point','Marker','o')
   r4(i)=sqrt((midpt_x1-d4)^2 + (midpt_y1-c4)^2);
end
r4;
avg_r4=sum(r4)/9;
avg_radius=(avg_r1+avg_r2+avg_r3+avg_r4)/4
avg_dia=2*avg_radius
```

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