Automated System of HESS Screen for the Diagnosis of Paralytic Strabismus Using Computer Aided Diagnosis

by

Muhammad Abubakar Yamin

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Prof. Dr. Shoab Ahmad Khan

College of Electrical & Mechanical Engineering

National University of Sciences& Technology

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DECLARATION

I hereby declare that I have developed this thesis entirely on the basis of my personal efforts under the sincere guidance of my supervisor Prof. Dr. Shoab Ahmad Khan. All of the sources used in this thesis have been cited and contents of this thesis have not been plagiarized. No portion of the work presented in this thesis has been submitted in support of any application for any other degree of qualification to this or any other university or institute of learning.

Muhammad Abubakar Yamin

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Dedicated to My Beloved Mother (Late) and Father

ABSTRACT

In Ophthalmology, Hess screen is an imperative instrument which is primarily employed for the measurement of paralytic strabismus. Strabismus is the state of eye in which eyes are not properly aligned with each other and patient complaint for double vision (diplopia). In this thesis we propose a model for the automation of traditional Hess Screen instrument for the diagnosis of strabismus. Presently Hess Screen Instrument is totally manual which consume lot of time of patient as well as ophthalmologist. We present a three stage system consisting of image acquisition, point extraction, plotting of Hess chart and computer aided diagnosis algorithm. First stage is composed of a digital camera which will take images of the HESS board and transfer it to a computer. In second stage image processing techniques are used to extract points from images to draw HESS plot, and in third stage an algorithm based on fuzzy logic is designed which will automatically diagnose the paralytic strabismus using statistics of the Hess graphs. This system is convenient, fast and has an ability to manage medical record with refinement. The evaluation of proposed system is performed by using dataset provided by well known local hospital.

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Chapter 1: Introduction

1.1 Overview

A crossed eye, or strabismus is a medical terminology which define the state in which both eyes are not properly aligned and do not focus at the same position at the same time. Strabismus arises when an eye twists in, out, up or down. This situation usually occurs due to poor control on eye muscle or a elevated quantity of farsightedness. Occurrence of strabismus could be happen at any age, but this disease is mainly frequent in toddlers and infantile children. It has been recorded that, strabismus affecting up to 5% of brood which includes boys and girls equally. Intermittent strabismus arises part of the time and in constant strabismus occurs all of the time. The six extraocular muscles which are attached to eye ball and they control the movement of eye as show in the figure 1.1. These extraocular muscles that direct eye movements are connected with brain using cranial nerves (CN) and receive signals through these nerves [1].

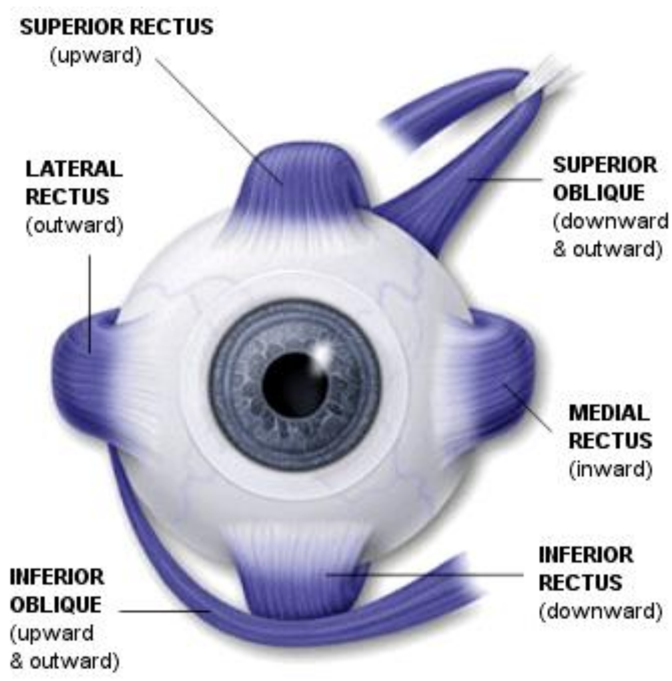


Figure 1.1 Eye Muscles Position [5]

Normally, both eyes exert jointly so they mutually focus at the identical position. When some neurogenic or mechanical crises increase with control of eye movement, an eye may twist up, down, out or in as shown in figure 1.2. The turning of eye could be clear all the time or may come into view only at sometime as when the individual is drained, sick, or has through a bundle of close work or reading. In some cases, the same eye may turn each time, while in other cases; the eyes may alternate turning [1].

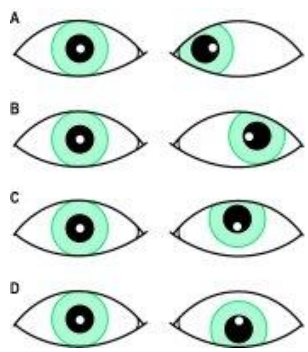


Figure 1.2 Eyes Position during strabismus

To avoid the double vision it is important to maintain the proper alignment of both eyes. This is also necessary for perceiving of stereopsis. Due to misalignment of both eyes, two different images will be perceived by brain. In start it could develop double vision (diplopia) and mystification as shows in figure 1.3. But with the passage of time brain learns to disregard the image from the deviated eye. If the deviation in eye remains steady and not properly treated timely, it cans results into permanent visual compromise in the affected eye. This condition of eye is known as amblyopia or lazy eye.

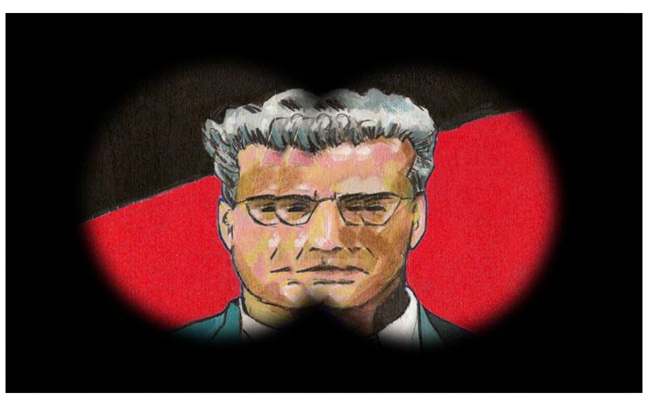


Figure 1.3 Vision during strabismus

Strabismus may be caused by the pathology of extraocular muscles, the fault in cranial nerves that convey signals to the muscles from brain (III, IV and VI cranial nerves), or due to some problem in control center of the nerves in the brain. Strabismus may also arise due to general health problems or trauma. Paralytic strabismus is due to defects in all or any one of III, IV and VI cranial nerves. Ophthalmologist use different methods to diagnose the strabismus.

HESS Screen test is one of the physical examination method used by most of ophthalmologist for the measurement of strabismus. The Hess screen test was intended by a renowned neurophysiologist Walter Rudolf Hess in 1908. HESS was honored with the Nobel Prize in 1949 for his research in the field of functional organization of the vegetative nervous system [2]. The basic principal of HESS screen test is foveal projection [3]. This test uses red/green goggles to break the binocular fusion of both eyes. This exploits the ocular deviation. Patient hold’s a green foster torch which he used to project on fix marks on the board.

HESS screen is a black tangent electronically operated screen with small red LED’s which is used for evaluating and grading strabismus. It consists of a chart separated by white lines into small segments of 5º divisions [4]. Where straight vertical and horizontal line crosses each other that point is called center point or fixation point. There are small red LED’s at the particular spots on the lines in the eight major meridians demonstrating locations 15º and 30º from the fixation point. Patient wears red/green goggles to break the fusion of red and green light. Eye covered with red glass is known as fixed eye and other eye which is covered by green glasses is testing eye.

The traditional Hess screen test procedure is mentioned as under: Patient is asked to sit at a distance of 0.5 m from the centre of the screen and wears red/green goggles. Test for the right eye conducted first pursued by the left eye. So firstly, green glasses will be on right eye and red glasses on the left eye. There are twenty five glowing LED’s marks on the board. Ophthalmologist or Orthoptist glows the LED’s one by one and patient will be asked to superimpose the green pointer of torch on the glowing red spot. If the eyes of patient are not diseased or restricted then he/she can point it successfully. If the patient is having restricted pathology or suffering from paralytic strabismus then he/she cannot place the green marker on the red glowing spot. After that the doctor notes down green mark’s position on Hess chart and then glow the next LED for the patient to carry out same procedure again. After that the doctor changes the red/green glasses position. Now green glass will be placed in front of left eye (testing eye) and red glass will be placed in front of right eye (fix eye) and doctor will repeat the same procedure again. In traditional Hess screen test doctor requires to turn on twenty five red marks for each eye and note down the location of each mark on the plot in darkroom. It makes this test vague and required lot of time by a specialist to perform this test.

An automated system for Hess Screen requires the precise automated measurement of muscles states (result recording), Patient record management and automated computer aided diagnosis (CAD). Little research has been undertaken in the field of Hess chart test. These techniques advances way of result recording, but have no automated system for diagnosis and analysis of result. So, ophthalmologists anticipate having a new automated system which must be simple to drive, less in cost, performance with nicety, and can support the automated diagnosis system. This motivate us to develop such automated system that is capable of doing the test automatically and give more precise results using CAD.

1.2 Motivation

The traditional way of Hess Screen diagnosis instrument is completely manual and time consuming. It takes about 20-30 minutes of a specialist to test a patient for paralytic strabismus. Automation of this process will able the specialist to complete the test in less time and to diagnose the disease more accurately. It has real time application in assisting the ophthalmologists for improved and efficient diagnosis of strabismus. This will allow developing a collaboration of engineering work with the medical field creating a new arena. This will help in bridging the gap that exists at the present between the engineering research and industry in Pakistan.

1.3 Scope of the Thesis

Statistics reveal that the doctor to patient ration in Pakistan is extremely low. We lack not only trained people but also resources to deploy modern instruments. Strabismus can be reason of amblyopia, when it occurs in infancy or get. in the condition of amblyopia the brain disregards input from the twisted eye. One study reported that 85% of adult strabismus patients "reported that they had problems with work, school and sports because of their strabismus." The same study also reported that 70% said strabismus "had a negative effect on their self-image. Hence there is need to identify the strabismus early and accurately. Any research in this situation can prove to be pretty useful at national level. The main objective of this research thesis is to develop reliable and accurate automated system will help out our ophthalmologists to diagnose the disease in less time and more accurately. Moreover technicians can do this test process which will be helpful in areas where ophthalmologists are not available. Patients will be treated promptly after diagnosis decreasing the ratio of people who become visual compromised due to paralytic strabismus. The main focus is to develop and automated CAD system diagnostic process which will be helpful to diagnose and classify the type of strabismus for better patient treatment and management.

1.4 Thesis Organization

This document contains the particulars of the overall information collected for the research work along with the proposed design of automated system of HESS Screen. Chapter 1 is the introduction and background to the research work. It is followed by the Chapter 2 of Literature Review that contains related researches and concepts. This chapter includes the basic knowledge of HESS Screen test, pathology of extraocular muscles of eyes, concept of strabismus and diplopia. Moreover, it also covers the previous relevant implementations on automation of Hess screen test.

Chapter 3 has detail of the proposed design of automated system. All details of proposed system are illustrated by the tables and figures in this chapter. Results of the implementation of proposed design and its discussion are presented in Chapter 4. Final is the Chapter 5 which briefly concludes the whole research and presents the opportunities of the work that can be done in future.

Chapter 2: Background & Literature Review

2.1 Introduction

This chapter briefly describes the details of research in the area of HESS Screen test. A number of research citations have been published in this concurrence. This literature review focus on the basic pathology of extraocular muscles of eye, reasons and tests for diagnosis of strabismus, study of basic principal of HESS Screen test and image processing & CAD algorithm design technique. The design parts mainly focus on the automation of HESS Screen so that the test could be performed in less time, without expert guidance and with more accuracy.

Already published citations includes concepts which advances way of result recording but have no automated system for performing test, analyzing and diagnosing disease using results. This chapter begins with the discussion fundamental concepts related to the pathology of eye muscles and their ocular movements. All of these issues also comprise the relevant medical terms and their definitions. It is then followed by the brief description about strabismus and its diagnosis techniques. Medical principal of Hess has also described in this chapter. In the end contribution of image processing in medical imaging and study of fuzzy logic for CAD algorithm designing has also been discussed.

2.2 Anatomy of Eye

The orbit is the hollow spaces in skull which contain the attachments of an eye. The orbit is a four sided, open into midline of the face and a conical hollow space that tip back into the head. Each orbit is consisting of an apex, four walls of skull and a base. Following bones/wall take part in formation of an orbit [6].

- **Superior (Roof):** Frontal and sphenoid bones
- **Lateral:** Zygomatic and Sphenoid bones.
- **Inferior (Floor):** Maxilla, Zygomatic and palatine bones.
- **Medial:** Ethmoid, lacrimal and frontal bones

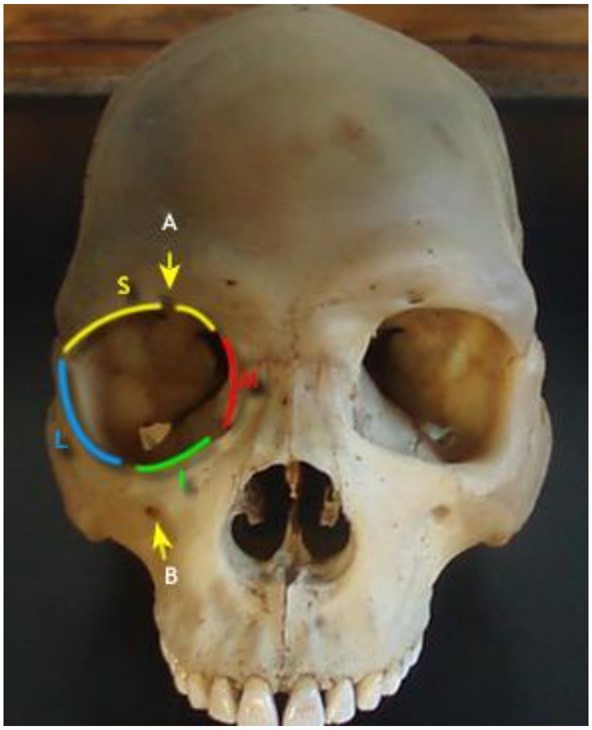


Figure 2.1 Orbital Wall Positions in Human Skull

The human eye (globe) is located in this orbit. The lateral and medical orbital walls are located at an angle of 45° with each other as shown in figure 2.2A. Hence the orbital axis which is the centre line of vision of eye forms an angle of 22.5° with both lateral and medial walls. For the sake of simplicity this angle is rounded off with 23°. When an eye look straight at some fix point with head erect (primary position of gaze), then visual axes form an angle of 23° with the orbital axis [6]. This can be seen in figure 2.2B.

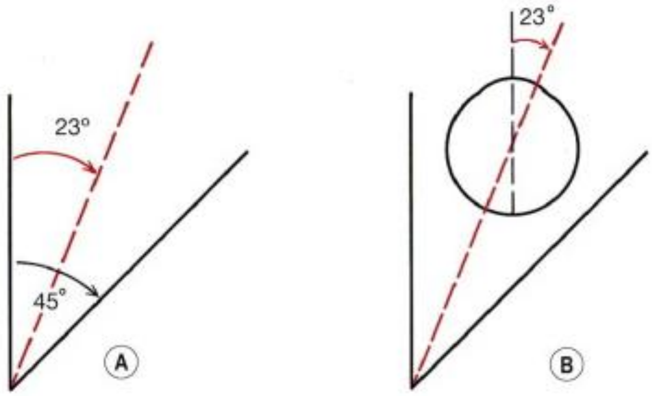


Figure 2.2 Orbital Wall Angle Positions

Listing plane is an imaginary coronal plane passing through the centre of rotation of the globe [6]. The globe rotates on the axes of Fick which intersect in the listing plane (Figure 2.3).

- On the vertical Z axis, the globe rotates left and right
- On the horizontal X axis, the globe moves up and down.
- On the Y axis, torsional movements (wheel rotation) take place which cross the globe from front to back.
- Intorsion happens when superior limbus rotates nasally and extorsion on occur when limbus moves temporal rotation.

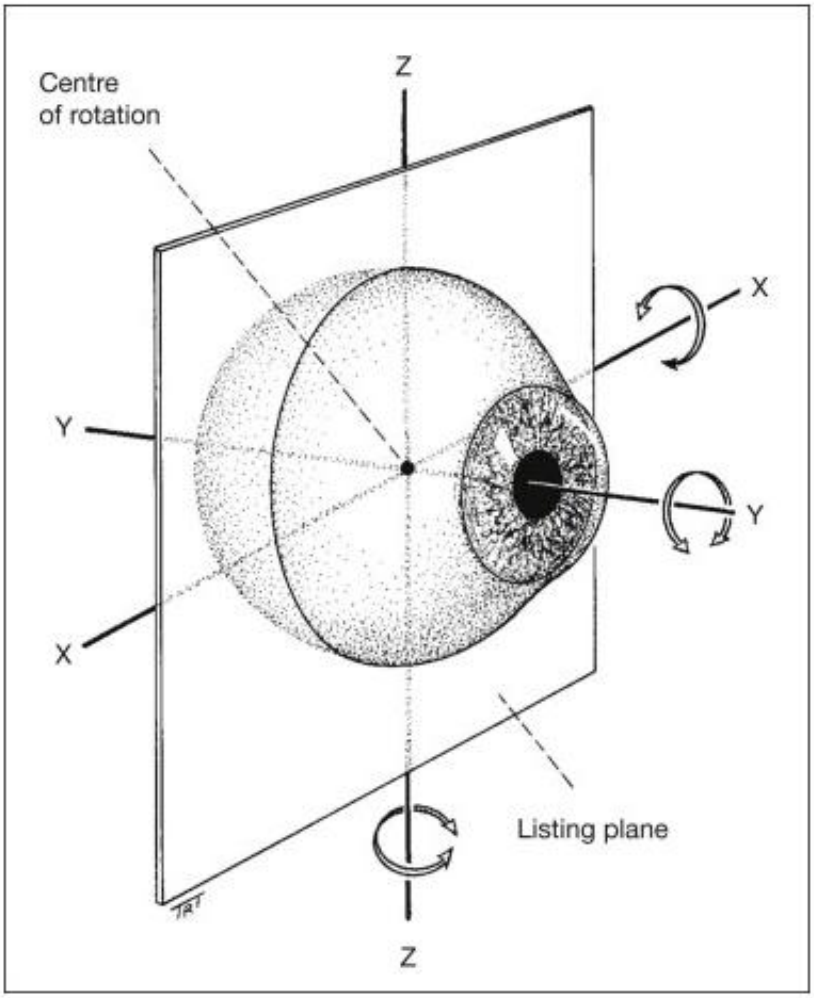


Figure 2.3 Listing Plane of Globe

2.2.1 Extraocular Muscles of Eye

The extraocular or extrinsic eye muscles are comparatively small in size but extremely powerful and proficient in work. There are six extraocular muscles which are attached with the eye ball, which take action to rotate the globe (eyeball) [6]. The moment of eye could be in horizontal, vertical or in antero-posterior axes. Following is the name of extraocular eye muscles:

1. **Medial rectus (MR)**
2. **Lateral rectus (LR)**
3. **Superior rectus (SR)**
4. **Inferior rectus (IR)**
5. **Superior oblique (SO)**
6. **Inferior oblique (IO)**

Following schematic (figure 2.4) shows the insertion of extraocular muscles in the right globe.

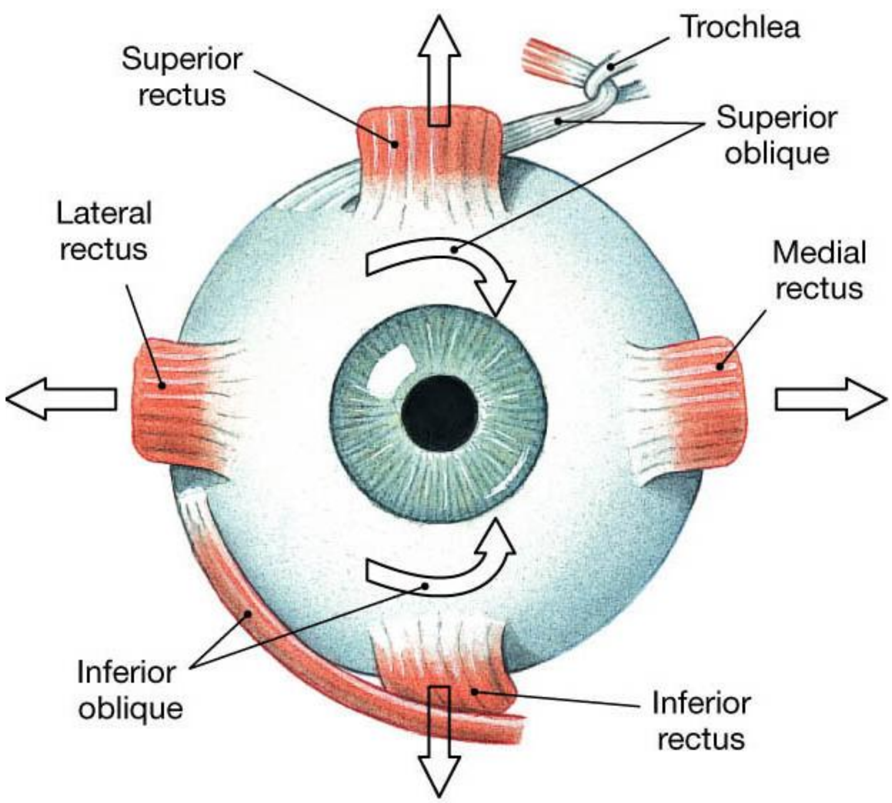


Figure 2.4 Extraocular Muscles Insertion in Globe [6].

2.2.2 Muscles Movement

Extraocular muscles of an eye work jointly with the muscle of other eye to move the eyes in different directions. The best way to know the working of the muscles is to study their movement in isolation (without other extraocular muscles in action) [6]. Role of movements of these muscles are described as follow:

- **Medical Rectus (MR):**
  - Play role to move the eye inward, toward nose, nasally.
  - Its action in prime position is adduction.
- **Lateral Rectus (LR):**
  - Play role to move the eye outward, away from nose, laterally.
  - Its action in the primary position is abduction.
- **Superior Rectus (SR):**
  - Its primary action is to move the eye upward which is called elevation.
  - Its secondary action is to rotate the top of eye nasally which is called intorsion.
  - Tertiary action is to moves the eye inward which is called adduction.
- **Inferior Rectus (IR):**
  - Its primary action is to move the eye downward which is called depression.
  - Its secondary action is to rotate the top of eye laterally which is called extorsion.
  - Tertiary action is to moves the eye inward which is called adduction.
- **Superior Oblique (SO):**
  - Its primary action is to rotate the top of eye nasally which is called intorsion.
  - Its secondary action is to move the eye downward which is called depression.
  - Tertiary action is to moves the eye outward which is called abduction.
- **Inferior Oblique (IO):**
  - Its primary action is to rotate the top of eye laterally which is called extorsion.
  - Its secondary action is to move the eye upward which is called elevation.
  - Tertiary action is to moves the eye outward which is called abduction.

MR and LR are known as horizontal rectus muscles because it moves the eye along the horizontal plane. Same like this SR and IR are known as vertical rectus muscles [6]. Consider each extraocular muscle in isolation without effect of any other muscle in movement; their actions are as provided in the table below:

Muscle	**Primary Action**	**Secondary Action**	**Tertiary Action**
Superior rectus	elevation	intorsion	adduction
Inferior rectus	depression	extorsion	adduction
Superior oblique	intorsion	depression	abduction
Inferior oblique	extorsion	elevation	abduction
Lateral rectus	abduction	none	none
Medial rectus	adduction	none	none

Table 2.1 Primary, Secondary and Tertiary Actions of Eye Muscles [6].

2.2.3 Law of ocular motility

2.2.3.1 Agonist-antagonist

These are the pair of muscles in the same eye which helps in the movement of eye in the same direction. The agonist muscle which is known as the primary muscle moves the eye in a specified direction and antagonist muscles act as a conflicting track movement muscle to the agonist. E.g. the LR of the right eye is the antagonist of the MR of same eye [6].

2.2.3.2 Synergists

This is the muscles which is situated in the same eye and it help to shift the eye in identical way. For example SR of right eye and IR of right eye are synergistically linked for elevation [6].

2.2.3.3 Yoke Muscles (contralateral synergists)

These are the pairs of extraocular muscles which is situated one in each eye that produces conjugate ocular movements. For example, yoke muscle of the right medial rectus is the left lateral rectus [6].

2.2.3.4 Sherrington Law

This is the law of reciprocal innervation which states that when a muscle contracts, to allow smooth movement of its direct antagonist relax to an equal extent. E.g. figure 2.5 show that when lateral rectus of left eye contracts the medial rectus which is direct antagonist automatically relaxes and vice versa [6]. Following table 1.2 shows the pair of extraocular muscles of eye.

For right eye res from top and right to left

Muscle	**Direct Agonist**	**Contralateral Synergists**	**Contralateral Antagonists**
Right MR	Right LR	Left LR	Left MR
Right LR	Right MR	Left MR	Left LR
Right SR	Right IR	Left IO	Left SO
Right IR	Right SR	Left SO	Left IO
Right IO	Right SO	Left SR	Left IR
Right SO	Right IO	Left IR	Left SR
Contralateral Antagonists	**Contralateral Synergists**	**Direct Agonist**	**Muscle**

For left eye read from bottom and right to left

Table 2.2 Extraocular Eye Muscles Pairs [6].

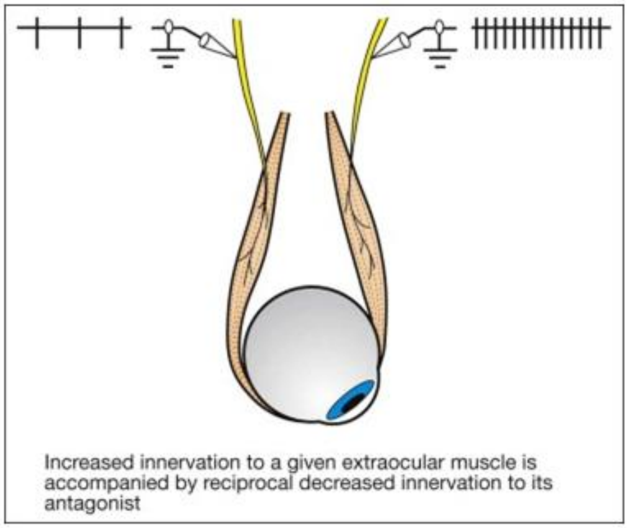


Figure 2.5 Sherrington Law of Reciprocal Innervation [6].

2.2.3.5 Hering Law

This is the law of equal innervations which states that during the movement innervation to one muscle of an eye to contract, generate an equal innervation to contract to its yoke muscle. Figure 2.6 shows this phenomenon. When right medial rectus contracts then equal innervation is produced to contracts its yoke muscle which is left lateral rectus [6].

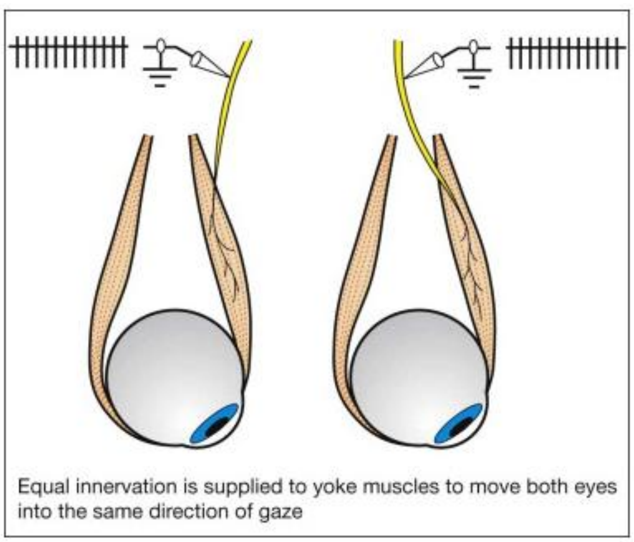


Figure 2.6 Hering Law of Equal Innervation of Yoke Muscle [6].

2.2.3.6 Ductions

These are the monocular movement around the axis of Fick. This is consisting of adduction, abduction, elevation, depression, intorsion and extorsion. These movements can be tested by covering the member eye and asking the patient to pursue a target in each track of gaze [6].

2.2.3.7 Versions

Simultaneous movements of both eye in the same direction is called versions. This is also called conjugate movement of eyes [6].

- Dextroversion (gaze right).
- Laevoversions (gaze left).
- Elevation (up gaze).
- Depression (down gaze).

These are the four movements of eye which bring the globe in the secondary position of gaze by rotating around either in the vertical Z-axis or horizontal X-axis [6].

- **Dextroelevation** (gaze right and up).
- **Dextrodepression** (gaze down and right).
- **Laevoelevation** (gaze up and left).
- **Laevodepression** (gaze down and left).

  These are the four oblique positions which bring the eye into the tertiary position of gaze by rotating the globe around the oblique axis [6].
- **Dextrocycloversion** (rotation to the right)

  In this version, eye globe rotates toward the right. In the action IR & IO of right eye and SR & SO of left eye take part.
- **levocycloversion** (rotation to the left)

  In this version, eye globe rotates toward the left. In the action SR & SO of right eye and IR & IO of left eye take part.

2.2.3.8 Vergences

This is the simultaneous movement of both eyes in the opposite direction. This is also known as disconjugate movements of eye. Simultaneous movement of both eyes toward nose (inward turning) is called convergence. Similarly outward movement from convergent movement is known as divergence [6].

At the same time no one cannot really diverge both eyes outward voluntarily from looking straight ahead. Because, the two lateral recti muscles cannot pull the eyes outward, simultaneously and voluntarily, while one is viewing something far away. However, some person is sleeping with his one eyes open, than divergence of an eye is possible involuntarily and momentarily, which can cause into temporary diplopia (double vision).

Figure 2.7 shows the versions and vergences movement of eyes.

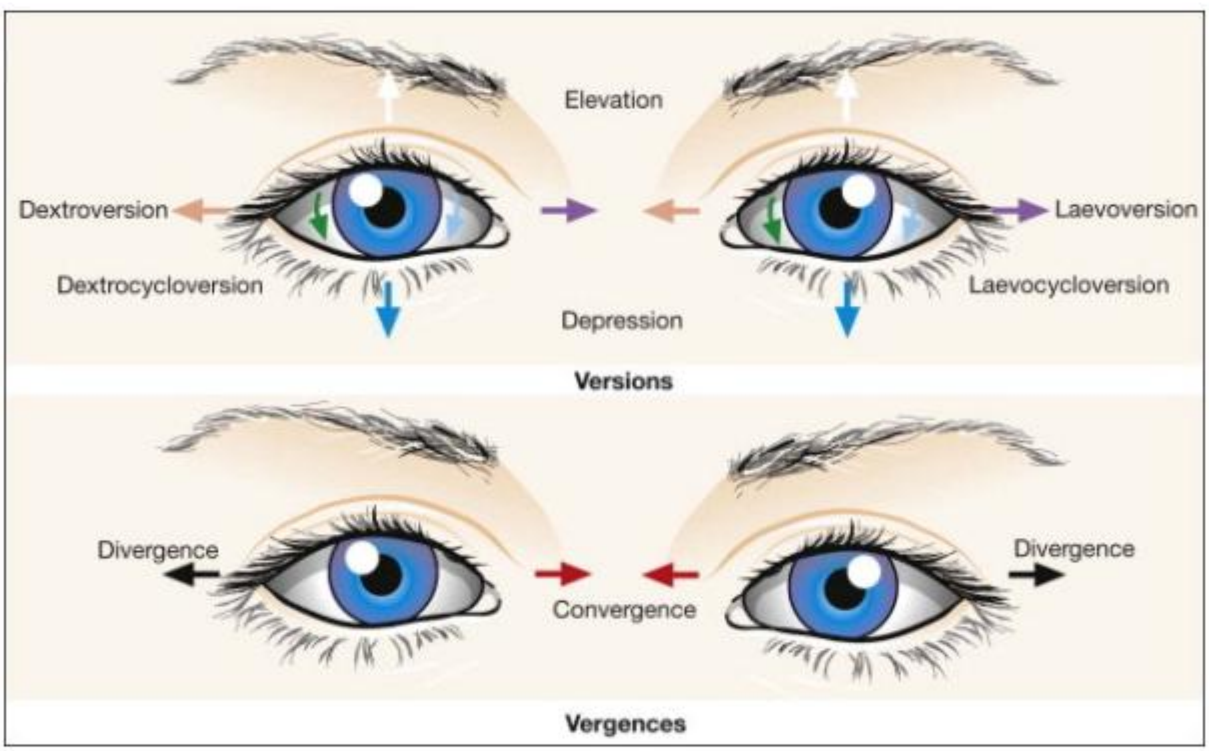


Figure 2.7 Binocular Movements (versions and vergences movment) [6].

2.2.4 Cardinal Positions of Gaze

The positions on which human eye can turned is known as positions of gaze. On these positions different muscles contribute to move the eyes. We can study the working ability of each muscle on these positions.

2.2.4.1 Cardinal Positions of gaze

These are the positions which are identified in which one muscle in each eye is principally responsible for moving the eye into that position. There are six cardinal positions of gaze. On these cardinal positions of gaze we can made assessments of vertical, diagonal and horizontal ocular movements which are formed by the six extrinsic muscles when multiple muscles of both eyes are working [6].

Following are six cardinal positions of gaze:

- Dextroversion (right lateral rectus and left medial rectus).
- Laevoversion (left lateral rectus and right medial rectus).
- Dextroelevation (right superior rectus and left inferior oblique).
- Laevoelevation (left superior rectus and right inferior oblique).
- Dextrodepression (right inferior rectus and left superior oblique).
- Laevodepression (left inferior rectus and right superior oblique).

At every position of gaze, every muscle of one eye is “yoked” with a corresponding muscle of the other eye which helps in the movement of eyes together in the specific direction. In figure 2.8, six cardinal positions of gaze are shown, along with the primary position and midline vertical positions (upward gaze, downward gaze) [6].

2.2.4.2 Nine Diagnostics

The positions in which deviations of muscles are measured are known as nine positions of diagnostic. These nine positions consist of six cardinal position, primary positioned, and elevation and depression position. In figure 2.8 we can see that when an eye move to a certain position extraocular movement of both eye works together to move globe on that specific position. For the upright gaze position we can see that SR of right eye working along with its yoke muscle which is IO of left eye. Similarly for the down left gaze position, IR of left eye is working along with its yoke muscle which is right SO. For the upward gazed position, SR+IO of right eye are working along its yoke muscles which are SR+IO in left eye. So by using these nine positions of gaze we can diagnose any type of disease which can occur in the extraocular muscles of eyes [7].

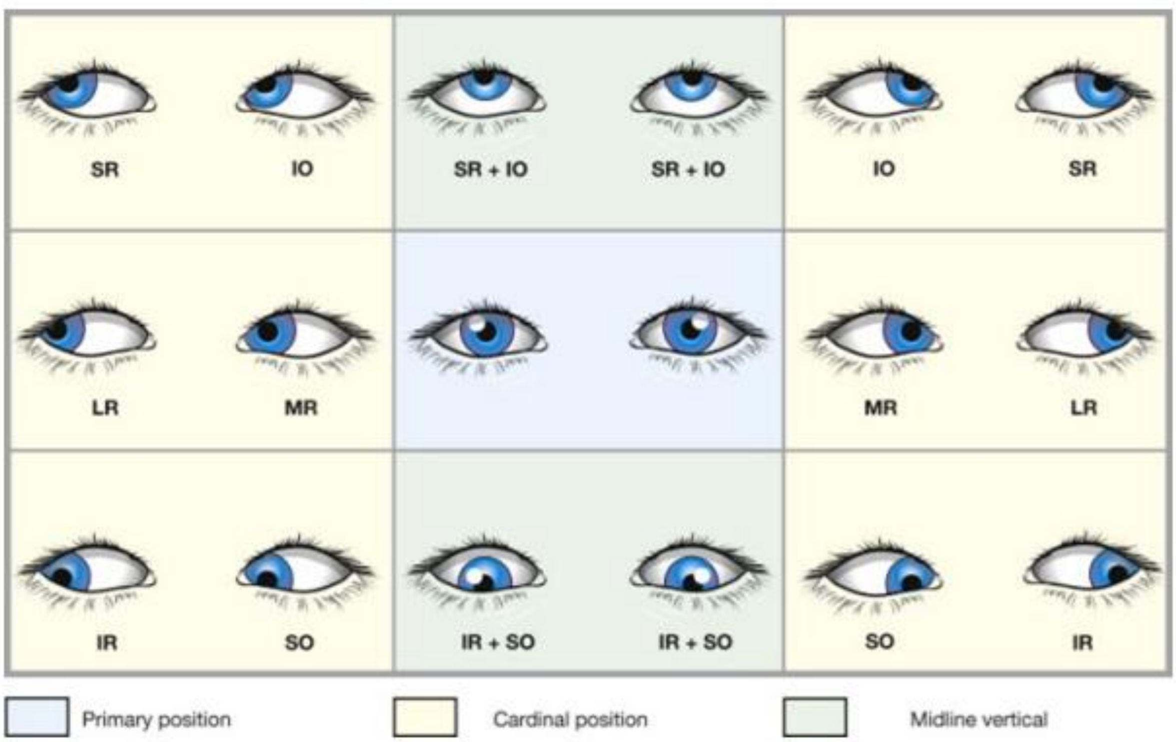


Figure 2.8 Diagnostics Positions of Gaze [6].

2.2.5 The Cranial Nerves

The extraocular muscles of eyes are innervated by the cranial nerves (CN) [7]. Following are the names of these CN:

- Cranial Nerve III (oculomotor nerve),
- Cranial Nerve IV (trochlear nerve) and
- Cranial Nerve VI (abducens nerve)

Following table represent the nerve supply to the extraocular muscles:

Cranial Nerve III	medial rectus muscle, superior rectus muscle, inferior rectus muscle, inferior oblique muscle
Cranial Nerve IV	superior oblique muscle
Cranial Nerve VI	lateral rectus muscle

Table 2.3 Nerve Supply to Extraocular Muscles [6].

Following formula can be employed to memorize the cranial nerve supply of six extrinsic muscles:

$$\mathbf{LR_6(SO_4)_3}$$

According to this expression, CN VI innervates the Lateral Rectus (LR), CN IV innervates the superior oblique (SO) and CN III innervates the remaining MR, SR, IR, and IO muscles. There are total six CN. Three CN for left eye and three CN for right eye [6]. Figure 2.9 shows the insertion of nerves in extraocular muscles of eyes.

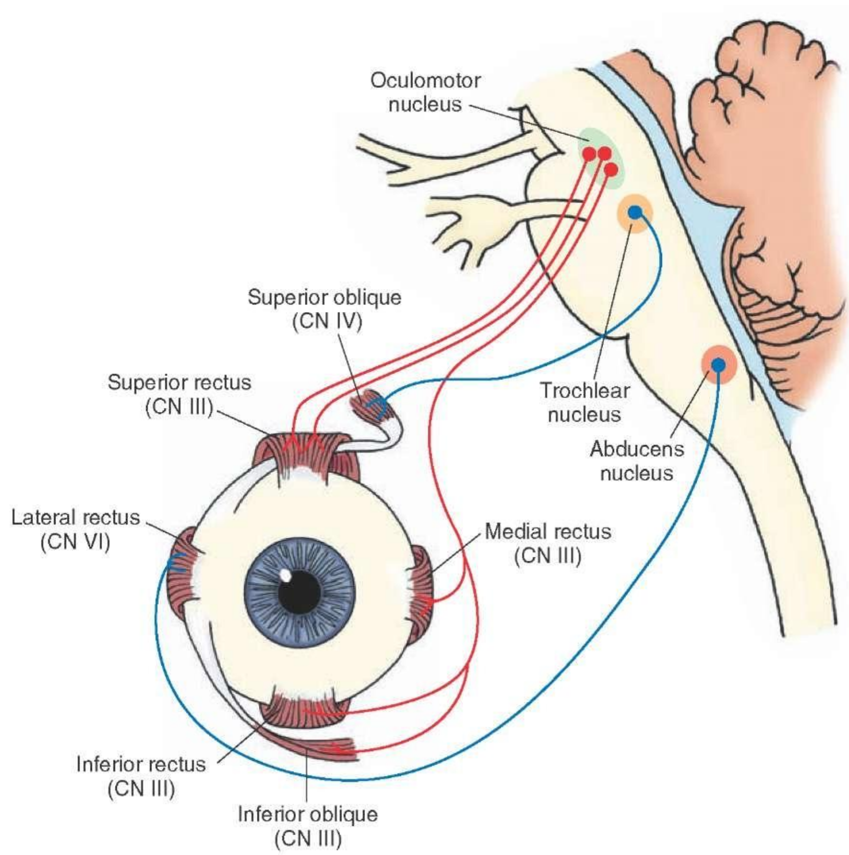


Figure 2.9 Diagnostics Positions of Gaze [7].

Arrangement of VI CN and IV CN are quite clear-cut. The paired right and left VI CN arise from the pons in the midbrain, and send their axons into the orbits to innervate the right and left lateral rectus muscles, respectively. Therefore, VI CN is responsible for abducting each eye (turning it to look laterally or toward the ear). The paired right and left trochlear nuclei are in the midbrain. Their axons, which make up IV CN, exit the midbrain, cross the midline, and send their axons into the orbits to innervate the left and right superior oblique muscles, respectively [7]. Therefore, IV CN is primarily responsible for turning each eye downward when it is already looking inward toward the nose. The relationship between the cranial nerve nuclei in the brainstem, the cranial nerves, and the muscles that the nerves innervate can be visualized in the schematic below (figure 2.10):

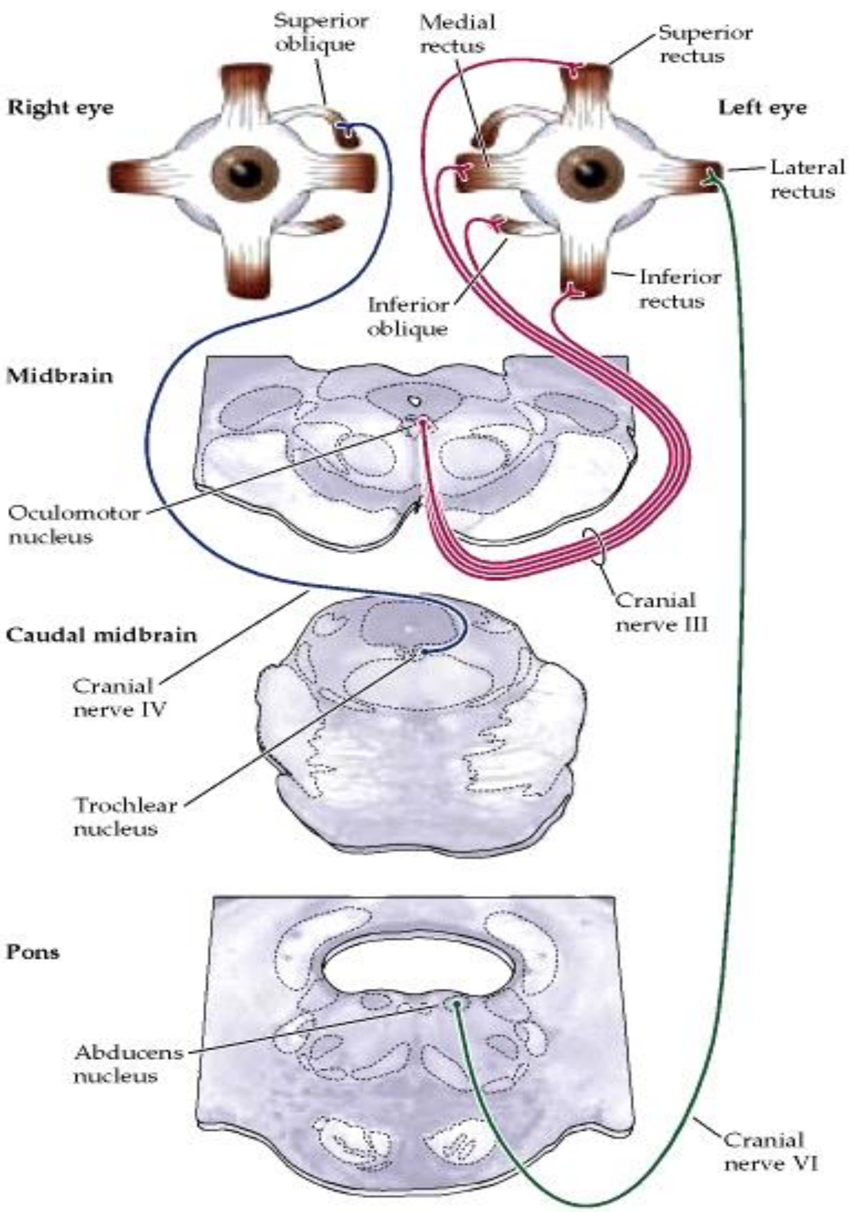


Figure 2.10 Diagnostics Positions of Gaze [7].

III CN is a bit more complicated, as it innervates all of the remaining extraocular muscles. Therefore, each oculomotor nucleus is actually made up of overlapping sub-nuclei, and each sub-nucleus sends its axons to innervate a specific extraocular muscle [7]. The right and left oculomotor nuclei are located in the midbrain. The axons from the right or left nucleus leave the midbrain and come together to form the body of the right or left III CN. As the nerve enters the orbit, it splits into the superior branch of III CN and the inferior branch of III CN. The superior branch of III CN innervates the superior rectus and the levetor palpebrae superioris. The lower branch innervates the medial rectus, inferior rectus, and inferior oblique [7]. A damaged cranial nerve will produce the same symptoms that would occur if the associated eye muscle is damaged. For example if cranial nerve VI is damaged, the eye will have the same motion as when the lateral rectus muscle is damaged. If cranial nerve III is damaged, the symptoms will be the same as if the four eye muscles controlled by III CN is damaged [7].

2.3 Strabismus

Strabismus or crossed eyes, a medical terminology, describes that condition of eyes in which both eyes don’t focus at the equal place at the identical time. For two eyes to be properly aligned, they should have comparable vision and focusing aptitude, and the muscles that move them need to work in mutually and in proper manner [8]. If a person obtains all these things in normal condition only then he/she can have binocular vision and depth perception, and can avoid seeing double (Diplopia). When misalignment in eyes occurs, then brain receives two different images from both eyes. In beginning, this may produce double vision (diplopia) and uncertainty, but eventually the brain will become skilled at to disregard the image from the turned eye. If the eye turning develop into constant and is not treated, it can escort to permanent decrease of vision in one eye. This condition is called as amblyopia or lazy eye. Strabismus can happen part of the time (intermittent) or all of the time (constant). Intermittent strabismus may worsen when the eye muscles are tired — late in the day, for example, or during an illness.

Symptoms of strabismus include:

- Eyes that look misaligned
- Eyes that do not appear to move together
- Frequent blinking or squinting, especially in bright sunlight
- Tilting the head to look at things
- Faulty depth perception
- Double Vision (diplopia)

2.3.1 Reasons of strabismus

Most often, there is no identical cause of strabismus. It can be reasoned by problems with the eye muscles, the nerves that broadcast signals to the muscles, or the control center in the brain that manages eye movements. It can also build up due to other general health states or eye injuries [9].

Risk factors for developing strabismus include [9]:

- **Family history –** individuals with parents or siblings who have strabismus are more likely to develop it.
- **Refractive error –** people who have a significant amount of uncorrected farsightedness may develop strabismus because of the additional amount of eye focusing required to keep objects clear.
- **Medical conditions –** people with conditions such as Down syndrome and cerebral palsy or who have suffered a stroke or head injury are at a higher risk for developing strabismus.

There are also many known causes, the amount of eyeglass correction required by the two eyes is vastly different; one or more absent, injured or defective nerves to the eye muscles, causing the muscles controlled by the nerve to function improperly; damage to an area of the brain dealing with eye movement or eye muscle control; injury from trauma that damages any eye muscles or nerves; blindness from disease or injury [9].

2.3.2 Classification of strabismus

Strabismus is classified according to the direction of misalignment [9].

Strabismus is classified as:

- Esotropia
- Exotropia
- Hypertropia
- Hypotropia.

When one eye turn inward (crossed eye), it is called esotropia. This is the most common type of strabismus which is also called as "convergent strabismus" because the eyes congregate or turn toward each other. In exotropia (wall eyes), one eye turns towards outside; it is also known as "divergent strabismus". Hypertropia is the condition in which one eye turns upward, it is the least common and in hypotropia one eye turns downward, this condition is also least common. In some people there is only one and same eye that deviates. While in some peoples this deviation shifts from one eye to the other. This is called alternating [9].

Other classifications of strabismus include:

- The frequency with which it occurs – either constant or intermittent
- Whether it always involves the same eye – unilateral
- If the turning eye is sometimes the right eye and other times the left eye – alternating.

On the basis of these classifications, strabismus can be paralytic or non-paralytic [8].

- **Non-paralytic (concomitant)** – The movement of both eyes are complete but only one eye is directing towards the target. There is a steady angle of divergence which is distinct to the direction of gaze. This tends to be the squint of childhood [8].
- **Paralytic (incomitant)** – In this condition, at least one extraocular muscle is under-action and the degree of squint is dependent on the direction of gaze (being largest when the globe is rotated towards the field of action of the relevant muscles or their associated nerve) [8].

We will discuss paralytic strabismus, because our thesis is specifically about this disease only.

2.3.3 Paralytic Strabismus (Incomitant strabismus)

Paralytic or incomitant strabismus takes place when there is restraint of ocular movement, which can be congenital or acquired. The major characteristics of incomitance are:

- **The angle of deviation-** increases as the eyes are turned in the direction of limitation of movement, and decreases when they are turned in the opposite direction, with the exception of some palsies due to mechanical factors, when movement may be limited in opposing directions.

- **The secondary deviation-** the angle measured with the affected eye fixating exceeds the primary deviation the angle measured with the unaffected eye fixating. The development of secondary comitance in long-standing cases can result in equality of the primary and secondary deviation.

2.3.3.1 Classification of Paralytic strabismus

Incomitant strabismus can be classified according to the underlying cause of the limitation of movement as:

- Neurogenic
- Myogenic
- Mechanical.

Incomitant strabismus is loosely referred to as 'paralytic strabismus' and the following terms are used:

- Paralysis, when no movement is possible;
- Paresis, when some movement is possible;
- Palsy, an older term that includes both paralysis and paresis and is generally used in the text.

This refers to the collection of states characterized by disease of the III, IV and VI cranial nerves. A nerve palsy may be lonely or there may be numerous nerves involved. Each nerve may be affected at any point along its course from the brainstem to the orbit. If the problem is in the brain stream from where all cranial nerves roots, then this can be classified as neurogenic strabismus, and if cranial nerves which communicates signals between brain stream and extraocular muscles of eyes got damaged or become weaker due to some reasons then this can be classified as myogenic strabismus. If extraocular muscles of eyes got damage or stuck between bones of skull, then this can be classified as mechanical strabismus. Main causes of all these strabismus is some injury on head or some accident that cause injury which can damage your brain tissues or nerve supplies. Myopathies may give rise to diplopia and restriction of eye movement; in severe cases there may be a degree of paralytic squint. Myopathies, unlike neuropathies, tend to be bilateral. Below is an overview of diplopia and cranial nerve palsies [9].

2.3.3.2 The Diplopia

This is the expression used when a patient observes an image in two dissimilar places. They are most usually side by side (horizontal diplopia) but may be one on top of the other (vertical diplopia) or, unusually, oblique to each other. It is imperative to differentiate monocular diplopia from binocular diplopia [9].

I. Monocular diplopia

This word is used when the double vision stays on occlusion of the uninvolved eye. Common causes include the presence of a refractive error, incorrect spectacle alignment and some media opacities (e.g. cataract). Less commonly, it can arise as a result of a dislocated lens, retinal detachment and central nervous system (CNS) disease.

II. Binocular diplopia

This is when the double vision is corrected when either eye is occluded. It may be intermittent, such as in myasthenia gravis and when there is intermittent decompensation of an existing phoria. Constant binocular diplopia is more typical of an isolated cranial nerve palsy (III, IV or VI cranial nerves), orbital disease (e.g. thyroid eye disease), post-surgery or post-trauma and with various CN's problems.

2.3.3.3 Isolated Nerve Palsies

Nerve palsy is a neurological state concerning the small blood vessels that influences the muscles that shift the eyes. With nerve palsy, there is an obstruction of blood stream to the nerves between the brain stem and extraocular muscles of the eye. Effect of isolated nerve palsies is discussed below.

I. Third nerve palsies

The third cranial nerve or III CN (also called the oculomotor nerve) supplies four of the six eye muscles, which are MR, SR, IR, and IO muscles. Some muscles that control the eyelid and the size of the pupil also get their supply from III CN. When the third cranial nerve is affected or acquires palsy, up-down motion of eye may be become limited because SR and IR (vertical plane muscles) got affected and one eye may twist away from your nose. The eyelid may drop and one may experience combined vertical and side-by-side double vision usually. In the figure 2.11, we can observe the patient is having a left III palsy CN. Eye lid of left eye is dropped and eye is twisted away from nose.

Figure 2.11 III CN Palsy a) Eye Twisted Away from Nose. b) Dropped Eye Lid [9].

II. **Fourth Nerve (SR) Palsies**

The fourth cranial nerve IV CN (trochlear nerve) is the thinnest and the longest cranial nerves, which make it mostly susceptible to traumatic injury. Palsy in IV CN could be reason for mixture of vertical, horizontal and torsional misalignment of the eyes. Typically, most noticeable feature is the vertical misalignment. Tilting the head towards opposite shoulder is common with superior oblique palsy. This abnormal head position allows improved alignment of the eyes, sometimes supporting in reprieve of diplopia. Figure 2.12 shows IV CN palsy eye but with the tilted head this misalignment can be improved [9].

Figure 2.12 IV CN Palsy a) Tilted head aiding improved position. b) CN IV affected eye.

III. Sixth Nerve (LR) Palsies

Sixth cranial nerve palsy innervates the lateral rectus muscle. The lateral rectus muscle drags the eye in the opposite direction of nose (laterally) and when the LR muscle is weak, the eye crosses inward toward the nose. This condition of eye is called esotropia. The mainly general reasons of VI CN are stroke, trauma, viral illness, brain tumor, inflammation, infection, migraine headache and elevated pressure within the brain. The state can be there at birth; however, the most ordinary source in children is trauma. In older persons, a minute stroke is the mainly frequent cause. Sometimes the reason of the palsy is not at all resolute even with wide investigation. Following figure 2.13 shows, affected eye with VI CN palsy. We can see that right is deviated towards nose which shows that lateral rectus muscles which pull the eye away from nasal side got weak and that's why eye is deviated towards nose [9].

Figure 2.13 IV CN Palsy Affected Eye [9].

2.3.4 Investigation of Strabismus

Strabismus is diagnosed through a comprehensive eye exam. Testing for strabismus, with special emphasis on how the eyes focus and move, may include:

- Patient History
- Visual Acuity
- Refraction
- Alignment and Focusing Testing (LESS Screen Test/HESS Chart Test)
- Examination of eye health

Our thesis is concern about the Hess Screen test, so we will be discussing Hess Screen in detail only [6].

2.3.4.1 Medical Theory of Hess Screen Test

The Hess screen test plot the dissociated ocular position as a function of extraocular muscle action and it helps in differentiation of paretic strabismus caused by neurological pathology from restrictive myopathy such as in thyroid eye disease or a blow-out fracture of the orbit, and recent onset paresis from long-standing. They also allow quantitative monitoring of progress in a range of conditions. The Hess screen test was intended by a renowned neurophysiologist Walter Rudolf Hess in 1908 [10]. Hess was honored with the Nobel Prize in 1949 for his research in the field of functional organization of the vegetative nervous system [10].

The basic principal of HESS screen test is foveal projection [11]. This test uses red/green goggles to break the binocular fusion of both eyes. This exploits the ocular deviation. Patient hold's a green foster torch which he used to project on fix marks on the board. HESS screen (figure 2.14) is a black tangent electronically operated screen with small red LED's which is used for evaluating and grading strabismus [12]. It consists of a chart separated by white lines into small segments of 5º divisions [12].

Where straight vertical and horizontal line crosses each other that point is called center point or fixation point. There are small red LED's at the particular spots on the lines in the eight major meridians demonstrating locations 15º and 30º from the fixation point. Patient wears red/green goggles to break the fusion of red and green light. Eye covered with red glass is known as fixed eye and other eye which is covered by green glasses is testing eye.

Figure 2.14 HESS Screen [13].

I. **Method**

The traditional Hess screen test procedure is mentioned as under:

Patient is asked to sit at a distance of 0.5 cm from the centre of the screen and wears red/green goggles. Right eye is tested first followed by the left eye. So, green glasses will be on right eye and red glasses on the left eye. There are twenty five glowing LED's marks on the board. Ophthalmologist or Orthoptist glows the LED's one by one and asks the patient to superimpose the green torch point on the glowing red spot. If the patient eye is not diseased or restricted then he/she can point it successfully. If the patient is having restricted pathology or suffering from paralytic strabismus then he/she cannot place the green marker on the red glowing spot. After that the doctor notes down green mark's position on Hess chart and then glow the next LED for the patient to carry out same procedure again [13]. Figure 2.15 shows the patient sitting in front of Hess screen during test. After that the doctor changes the red/green glasses position. Now green glass will be placed in front of left eye (testing eye) and red glass will be placed in front of right eye (fix eye) and doctor will repeat the same procedure again. In traditional Hess screen test doctor requires to turn on twenty five red marks for each eye and note down the location of each mark on the plot in darkroom and in the end doctor have to join all 25 points of each eye in a specific way to make the valuable Hess screen plot. After plotting the Hess Plot, Doctor does the interpretation. It makes this test vague and required lot of time by a specialist to perform this test. Patient head should remain straight during the whole test. This is important to remain the fovea in the same position throughout the test [13].

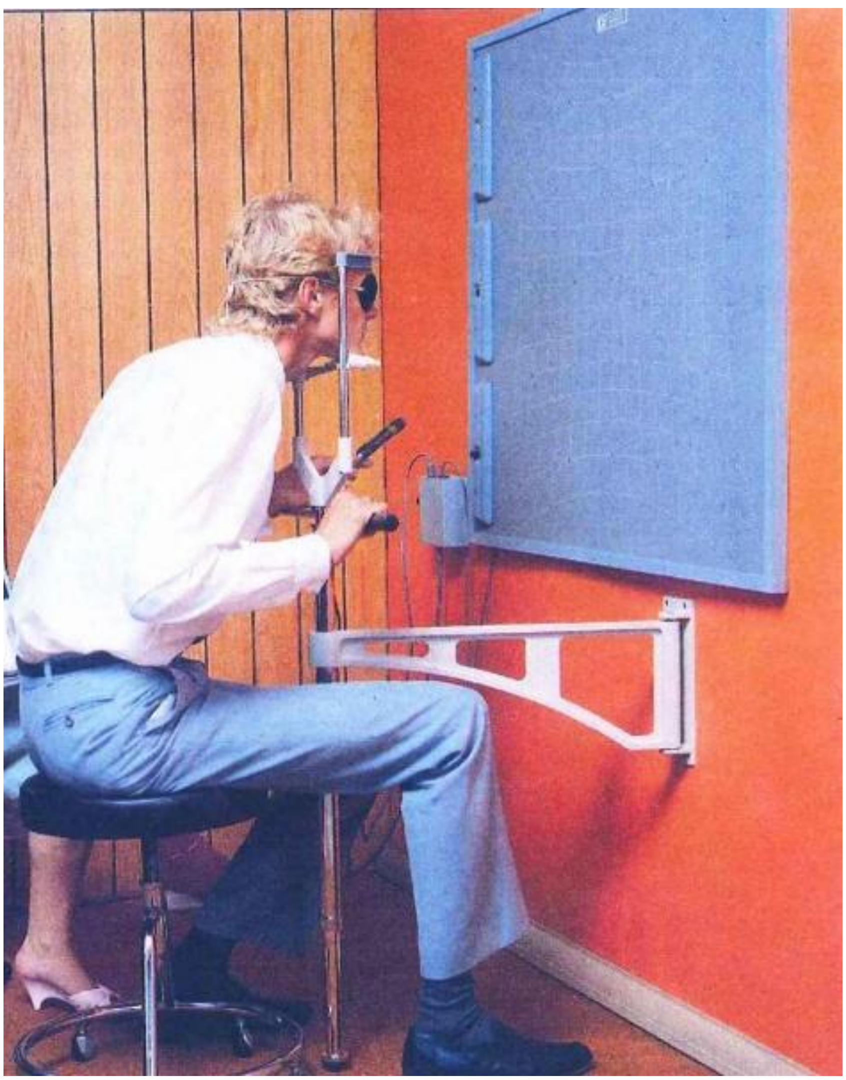


Figure 2.15 Patient position during HESS Screen Test [13].

II. Hess Chart Interpretation

The interpretation of Hess chart is done on basically three broad parts [13].

a) Hess Chart Inner Field Analysis

The basic principal of Hess chart is foveal projection therefore higher field belongs to the higher eye. After drawing the plot of both eyes, doctor visually investigates that which eye plot have smaller inner field area. Graph with smaller inner field area has to be considering as diseased eye. Hence this part of interpretation is very important and should be performed very carefully [13].

b) The Fixation Point Analysis

Fixation Point is the center point of the Hess Plot. This is also called the ‘primary position of eye’. This position is considered as reference point which is at zero degree. In this position none of the muscles is contracted or relaxed. Position of the central dot indicates whether the deviation is in primary position or not. The position of the central dot is to be seen both fixing right eye and fixing left eye. Deviation of this point from origin tells us about the state of tropia. Zero to five degrees deviation has considered as normal. Five to eight degrees deviation has considered as insignificant and deviation greater than eight degrees has considered as significant. If this point is deviated upward this shows the presence of hypertropia and if point is deviated downward this shows the presence of hypotropia. Similarly deviation towards nose (nasally) represents esotropia and outward deviation shows exotropia presence. Hence this analysis is important in diagnosis of tropia in the eye [13].

c) Hess Chart Outer Field Analysis

Outer Square is situated at thirty degree from the origin. Outer square analysis is important for analyzing the states of muscles as normal, underacting or overacting. Only six points of outer field is important for analysis. Each point will represent one of the extraocular muscle of eye. Four corner points of outer square will represent the four vertical plane extraocular muscles (Inferior Rectus, Inferior Oblique, Superior rectus and Superior Oblique) and middle points of right and left side of square represent the horizontal plane extraocular muscles (Medial Rectus and Lateral Rectus). The variation in the size of the Hess chart inner and outer field of each eye is because of the Hering’s law. As we have mentioned above that, small field belongs to the eye with primary limitation of movement. The points which have inward movement from its fixed point are considered as underacting of that point. Similarly the points which have outward displacement from their fixed point can be considered as overacting points. Maximum displacement occurs in the direction of the main action of the overacting contralateral synergist in the larger field. Normal range has been defined under the limit of $5^{0.}$ If the point is in the range of 5^0 inward or outward from its fixed point, then it should be considered as normal or insignificant overacting or underacting [13].

If the inward and outward displacement is less marked, secondary underactions and overactions are present as a result of the development of muscle sequel. Outer field should be examined for small underactions and overactions which may not be apparent on the inner field. A narrow field restricted in opposing directions of movement denotes a mechanical restriction of ocular movement. Equal sized field denote either symmetrical limitation of movement in both eyes or a non paralytic strabismus [13].

2.4 Image Acquisition

Image acquisition is the first stage of any vision system. A digital camera or USB webcam is used for acquiring the real time images of the Hess Screen board during the test. This camera gives color images containing red and green points to the computer for further processing. These images can be stored in system for evaluating the results later or we can send these images via internet of network to some distance centre for analysis of results from some expert ophthalmologist or for storing the data in some better and safe location. Benefit of storing data is that we can use these results later for comparison with the after treatment results.

2.5 Preprocessing (Image Enhancement)

Preprocessing is the first step of this automated system and it should be done before further processing. This step is necessary to get better results with good performance time. The purpose of this step is to remove the noise and unnecessary regions from the images. So that, results obtained should be according to the requirement. If we don’t use this step then our system will give us poor results with noisy images. We have used the median filter for this purpose.

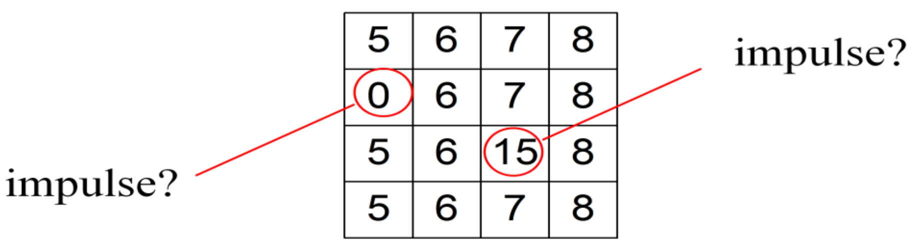
2.5.1 Median Filter

Median filter is and order statics spatial filter that is based on ordering the pixel value that make up the neighborhood operated on by the filter. This filter removes the noise in an excellent way and smoothen the image without preserving the edges and useful information n the image [14].

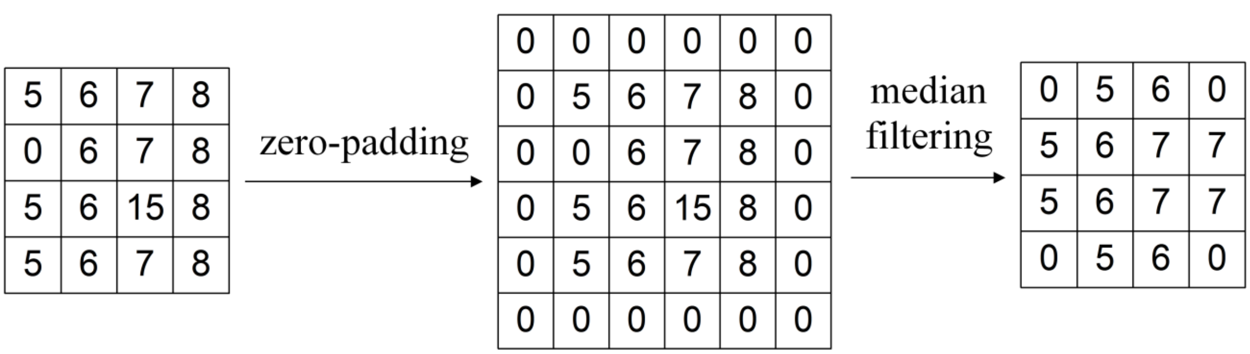
$$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{median}\{g(s,t)\} \quad \text{.................... (2.1)}$$

The equation 2.1 shows that, in an image a window of S x T size will be moved and in each iteration it will arrange the element lying under that window in ascending order in an array. After arrangement this filter will select the value present in the centre (mid) of the array and replace it with the current pixel which is the centre of that filter. By using this filter we can remove noise with nicety and without preserving the edges. This phenomenon of median filtering is given below in the form of matrices [14].

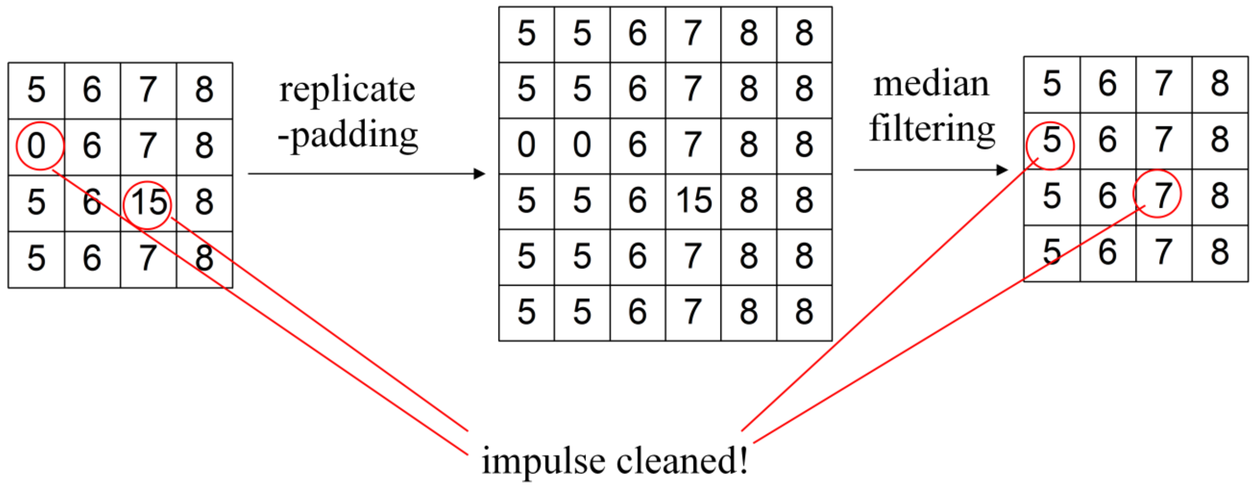
- A 4x4 grayscale image is given by. Impulses can be seen in the image. Our aim is to remove these impulses and smoothen the image.



- Filter the image with a 3x3 median filter, after **zero-padding.**



- Filter the image with a 3x3 median filter, after **replicate-padding** at the image borders**.**



We can see that, after applying median filter impulses in the images has been filtered out without preserving other information the images. Hence, such filter has been used to increased increase the results accuracy after preprocessing [14].

2.6 Fuzzy Logic

The idea of Fuzzy Logic (FL) was visualized by Prof. Lotfi Zadeh,of University of California at Berkley, and offered not as a control method, but as a method of processing data by letting partial set membership rather than crisp set membership or non-membership.

FL is used to map the nonlinear input data set to a scalar output data. FL is problem solving control-system methodology that can be implemented in system ranging from simple, small embedded microcontroller to larger networked based workstation which used for data acquisition and control purposes. FL can be executed in hardware, software or a mixture of together.

By using this simple sense FL of we can conclude some specific results based on ambiguous, noisy, vague or noisy information in input. FL concluding approach is similar how a person would make decision only much faster [15].

Fuzzy Logic System is consisting of three parts: Fuzzifier, rules & inference engine and defuzzifier. FL takes the fuzzy input and by using the membership function it makes this input value member of a specific function according to its nature. These components of fuzzy logic architecture are shown in following figure 1.18:

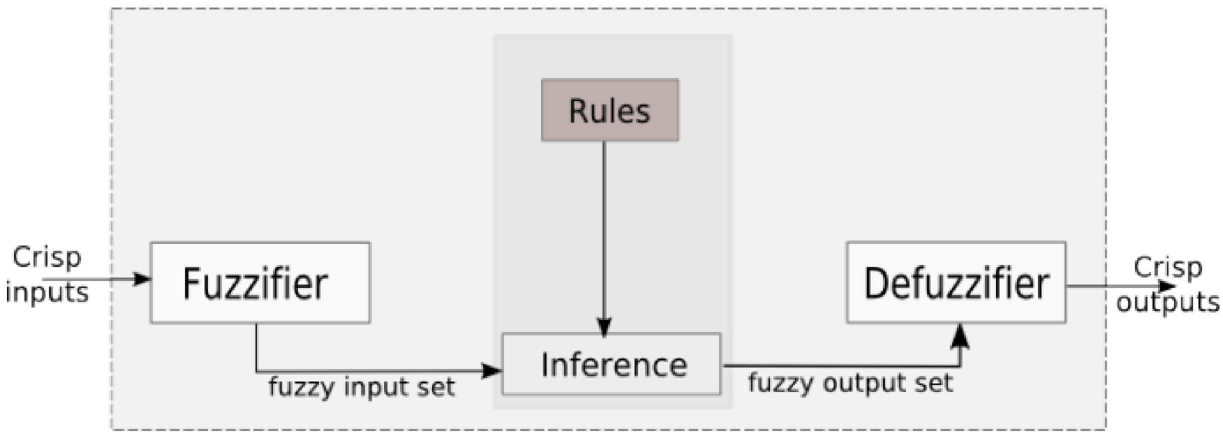


Figure 2.16 Fuzzy Logic System Architecture [15].

2.6.1 Fuzzifier

Firstly, a crisp set of input is collected at the input and altered to a fuzzy set using fuzzy linguistic variable/terms and membership functions. This step is called fuzzification. Fuzzy linguistic variable are the variables present on input or output of the system whose values are words or sentence from a natural language in its place of numerical values [15].

E.g. let us consider the example of air conditioner. Let temperature (t) which is representing the temperature of a room, be the input linguistic variable present at the input of the system. This succeed the temperature we have to define the temperature in term such as “too-cold”, “cold”, “warm”, “hot” and “too-hot” which are the linguistic values of the temperature. This can be done by using the membership function [15].

Membership function is used to map the non-fuzzy input values into fuzzy linguistic fuzzy terms. In the figure 1.19 we can see a set of membership functions which takes the temperature as input and according to the range they defined the input in fuzzy linguistic terms.

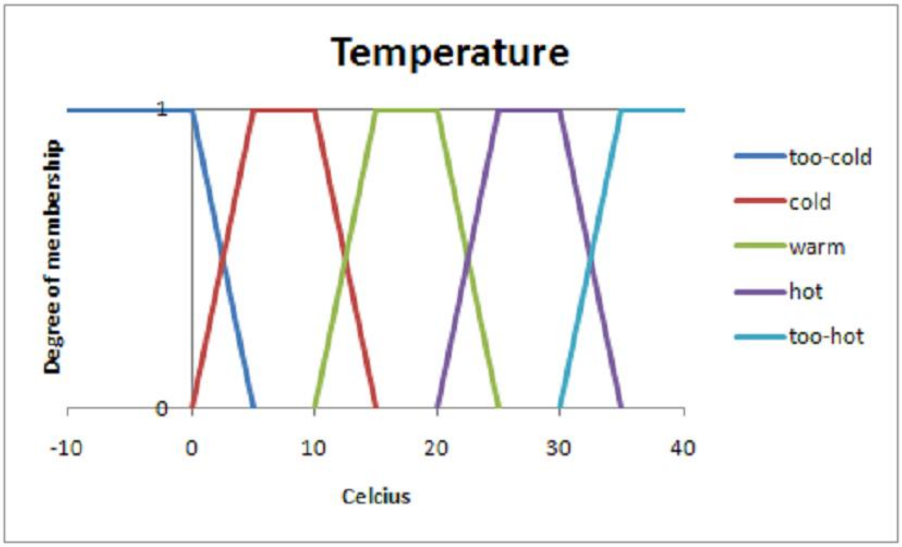


Figure 2.17 Membership Functions for T (Temperature) [15].

When an input will occur, then this membership function according to its range will convert that input into fuzzy linguistic term. E.g. if we have 23^0 at the input then this membership function will convert the input as warm for further processing [15].

2.6.2 Rules and Inference Engine

In Fuzzy Logic systems, a rule base approach is put up to control the output of the system according to the input. These rules are simply based on IF-THEN rules with some condition and then conclusion [15].

Following is an example of the rules implemented for air conditioner temperature control system.

IF (temperature is cold OR too-cold) AND (target is warm) THEN command is heat
IF (temperature is hot OR too-hot) AND (target is warm) THEN command is cool
IF (temperature is warm) AND (target is warm) THEN command is no-change

We can also represent these rules in the form of matrix. Table 1.4 shows the inference rules in the form of table [15].

temperature/target	Too-cold	Cold	Warm	Hot	Too-hot
Too-cold	No-change	heat	heat	heat	heat
Cold	cool	No-change	heat	heat	heat
Warm	cool	cool	No-change	heat	heat
Hot	cool	cool	cool	No-change	heat
Too-hot	cool	cool	cool	cool	No-change

Table 2.4 Fuzzy Rules Matrix **[**15].

2.6.3 Defuzzification

After the applying rules on the input and getting the conclusion, the overall results are a fuzzy value. Now we have to defuzzify these values to obtain a crisp output. Here we will use defuzzifier. Defuzzification will be performed according to the membership function of the output variable. This defuzzification is convert the fuzzy linguistic terms into some crisp numeric values which will be used as output of the system. Figure 1.20 shows defuzzification of a process [15].

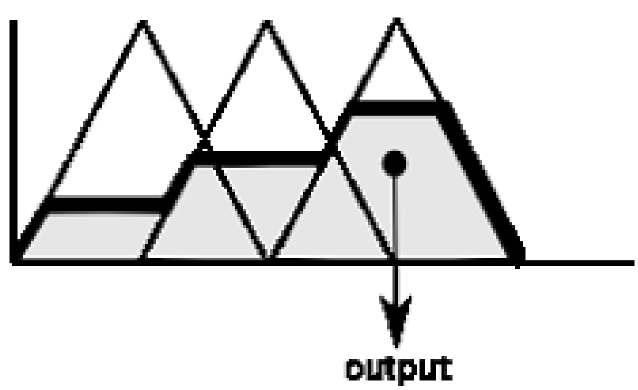


Figure 2.18 Defuzzification step [15].

2.6.4 Previous Work

Little research has been undertaken in the field of Hess Chart test. In 1996, Wei Bingzhang urbanized a new technique which takes images of the light mark released by patient using a TV camera and then exercised correction algorithm based on Geometric distortion of space image and as a final point printed the outcome of HESS chart test. All of the system management including acquiring images was executed by an unusual signal lamp which was connected with computer using wireless [16].

In 1998, Ma Zonglian build up an improved technique which utilized green facular electric torch attached with planar Increment angle encoder. It drives angle indication to a sole chip to produce the outcome of Hess chart test [17].

Cao GuiLian presented a system of diagnose and analysis which compare patient's Hess chart with the already diagnosed Hess chart stored in the database to differentiate the muscular torticollis and ocular torticollis [18].

In 2007 Liping Wang proposed a new digital instrument for strabismus diagnosis. He replaces the traditional Hess Screen Instrument with a 20" LCD screen and implemented java based testing software. His system was capable of holding medical record or patients [19]. These techniques are intricate to handle, and its take lot of time and expert assistance to perform the test. These techniques advances way of result recording, but have no automated system for diagnosis and analysis of result.

Chapter 3: Design and Implementation

The traditional Hess screen is an imperative instrument which is primarily employed for the measurement of paralytic strabismus. This instrument is useful for checkup of extraocular muscles of eyes. It provides quantitative analysis about muscles states and category of strabismus. In hospital, the results are used to diagnose the disease as paralytic strabismus or restriction in orbit, so that the patient can be treated accordingly. The conventional Hess screen is difficult to operate, more time consuming and manual in use. Automation of traditional Hess screen will able the ophthalmologist to perform the test in less time and diagnose the disease with nicety, quickly and more accurately. These techniques which we have discussed in last chapter are still intricate to handle, and its take lot of time and expert assistance to perform the test. These techniques advances way of result recording, but have no automated system for diagnosis and analysis of result. So, ophthalmologists anticipate having a new automated system which must be simple to drive, less in cost, performance with nicety, and can support the automated diagnosis system.

3.1 Proposed Technique

In this thesis we proposed a new automated system of Hess screen test for strabismus diagnosis. This technique incorporate image manipulation and software based diagnosis algorithm which detects the type of strabismus as paralytic or restriction. Our proposed technique is based on the method of creating traditional Hess chart, medical theory of Hess chart and characteristics of extraocular muscles of eyes.

In this chapter we have discusses the different component of our proposed automated system. This system is composed of computer aided diagnosis (CAD) algorithm, digital camera, computer with printer, traditional Hess screen, green laser torch and red/green goggles. Figure 3.1 shows the schematic of our proposed system.

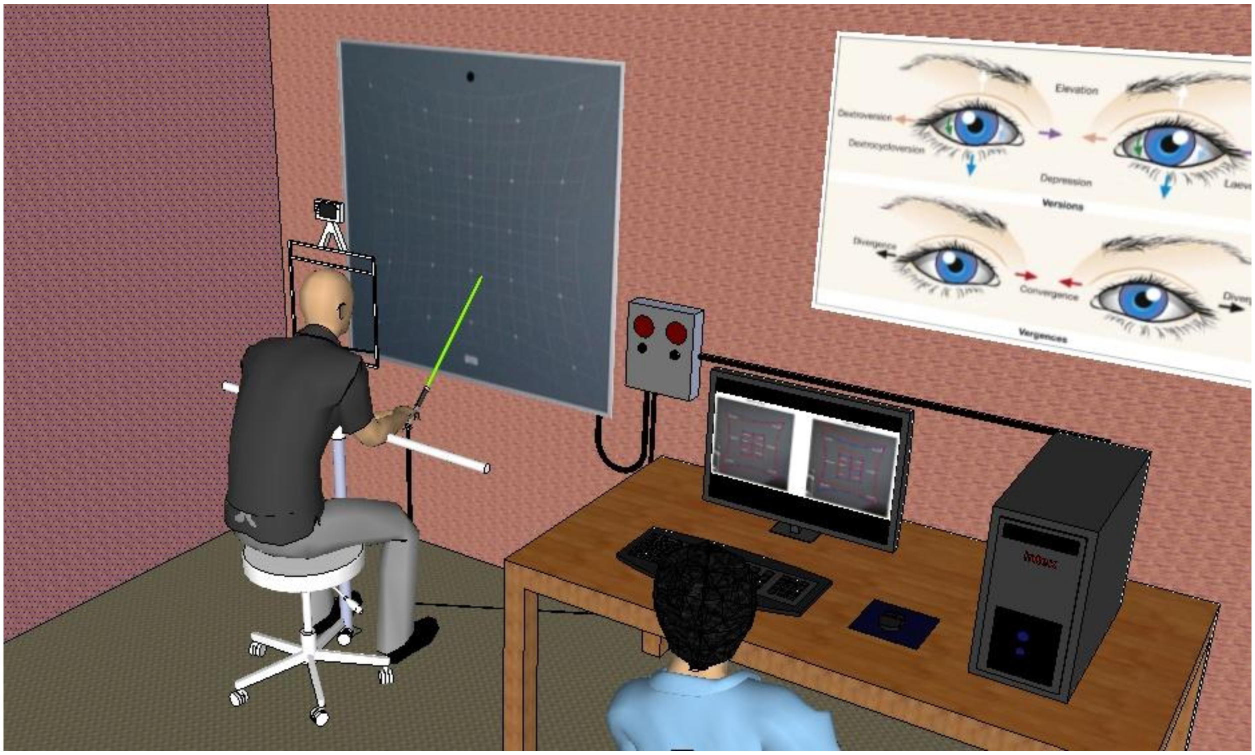


Figure 3.1 Schematic of Proposed Technique.

We automate the traditional Hess charting method along with the self diagnosis system instead of replacing or making any change in it. It increases the rank of the intelligent diagnosis and scrutinizes records wisely, and requires less effort by specialist to perform the test. The automated system of Hess screen for strabismus diagnosis is comprises of automated Hess screen check up, patient's medical record management system and automated result diagnostic system. It offers amalgamation function of automated diagnosis of strabismus, data documentation and scrutinize.

In our proposed technique, we have connected the Hess board control box, green torch and camera with the computer for automation purpose. A MATLAB based GUI program will control the working of all these components. Camera which is hooked on the chin stand is used to take images and give input in digital form. Camera and Hess screen, will be operated through computer.

Major steps involved in the automation of this system include:

1) Hess screen image acquisition,
2) Pre-processing of red/green channel image,
3) Intensity based red/green point extraction,
4) HESS chart plotting,
5) Hess chart analysis
6) Automatic Diagnosis System (CAD algorithm)

Figure 3.2 shows the flow diagram of the proposed technique:

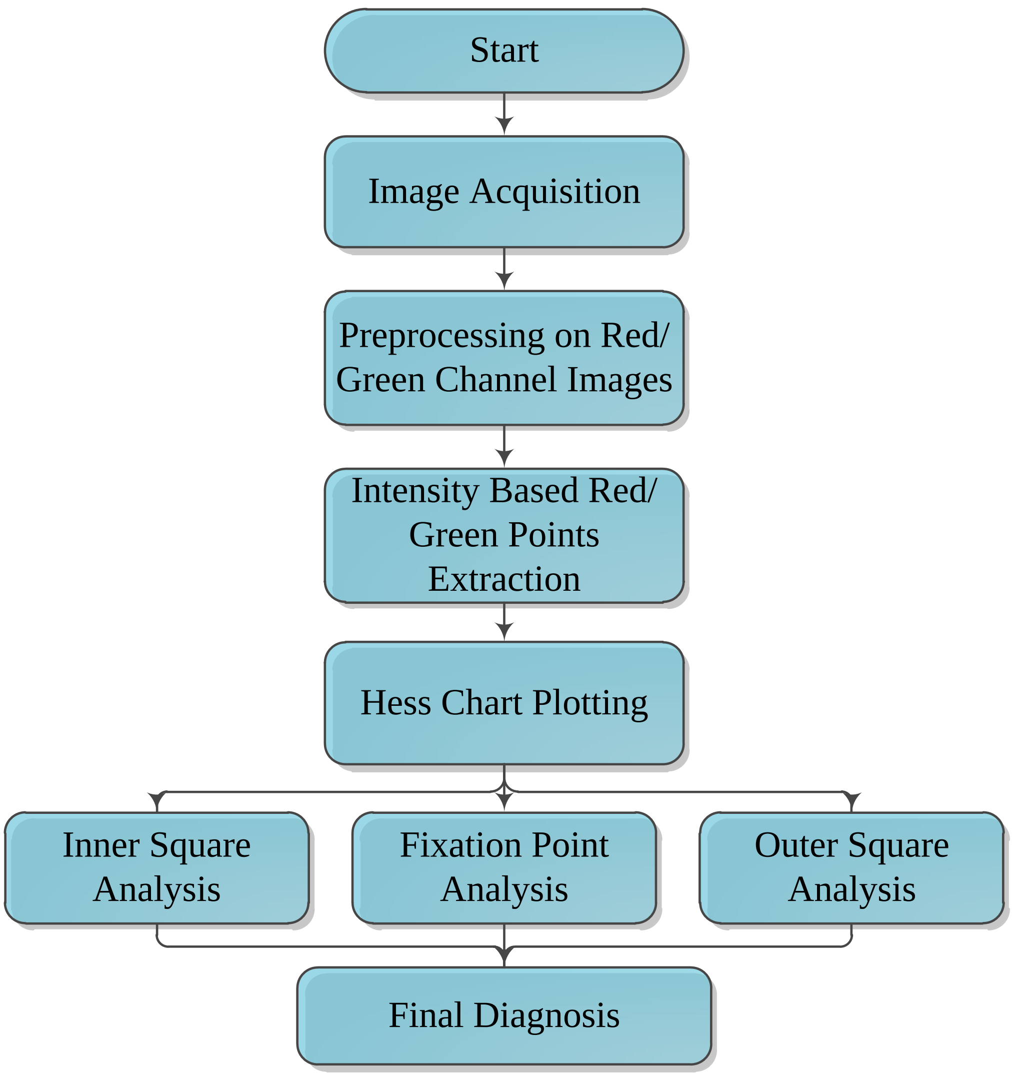


Figure 3.2 Flow Diagram of Proposed Technique.

3.2 Image Acquisition

First stage of proposed system is image acquisition. We used the traditional Hess screen instrument without making any change in it. This instrument consists of traditional Hess screen, red/green goggles, green torch and digital webcam. Hess screen containing red LED's is connected to computer. In computer a MATLAB based GUI software will control the LED's on/off sequence. Webcam is mounted on the top of patient chin stand and connected with computer using universal serial bus (USB) port (figure 3.1). This camera will be used to take the images during the test and to make the input digital.

Testing procedure is same like traditional Hess charting (discussed in chapter 2) but doctor have to press enter key to take color image of the board using webcam instead of noting green marks on a Hess chart. This will make the test east to conduct and don't require the expert advice during test. After taking a RGB image, camera will send the image contains current position of red and green marks to the computer. After acquiring the image of current location, computer automatically turns on the next LED and patient has to position green marker for next red LED. Operator will repeat the same procedure to complete the test. Figure 3.3 shows the grabbed images during test.

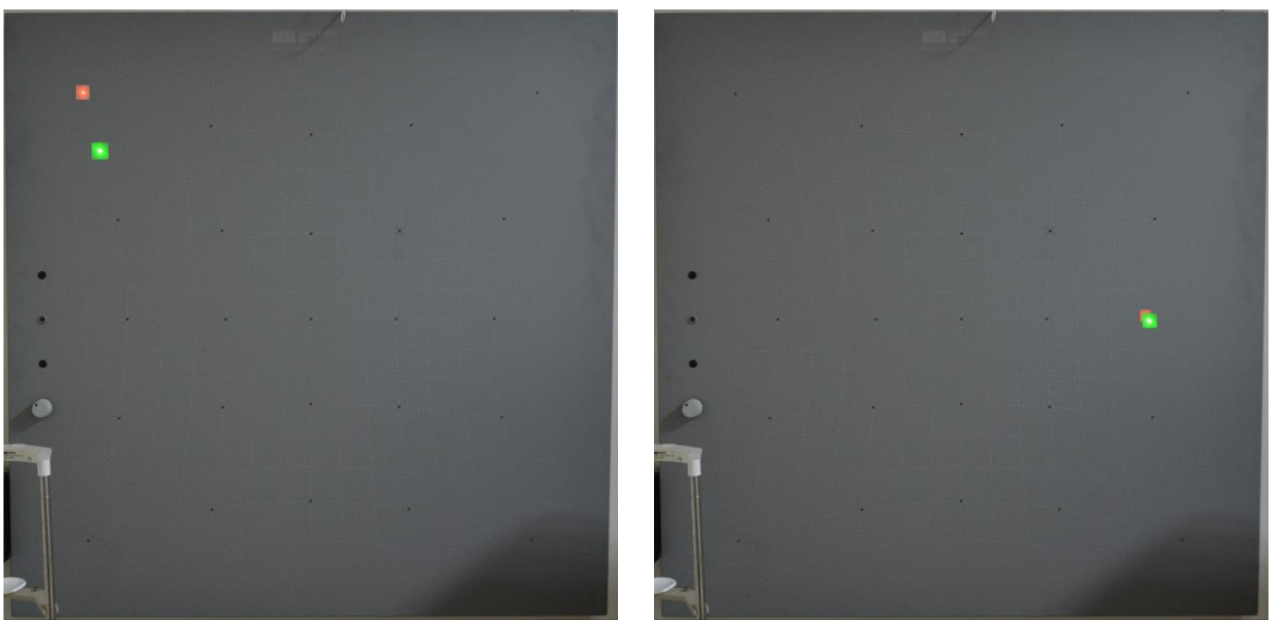


Figure 3.3 Images Acquired During Test Using Camera

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3.3 Red-Green Point Extraction

At this stage, we have to extract the red-green point from the grabbed RGB image. There are numerous image segmentation techniques available to extract the color points from an image. In our proposed system we have used a new technique to extract red-green point from the image. This technique is robust and can find the location of points in very less time. Because of these advantages this technique can be used in real time system. Figure 3.4 shows an RGB image with its three separate frames of Red, Green and Blue color.

(a)

(b)

(c)

(d)

Figure 3.4 RGB Image a) RGB Image b) Red Channel Image c) Green Channel Image d) Blue Channel Image.

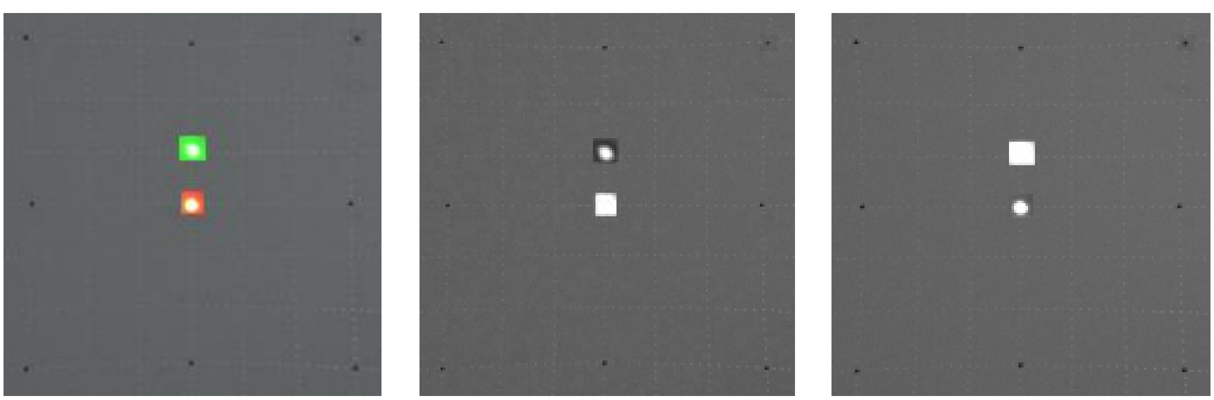
From the figure 3.4 we can see that, in the different frames of a RGB image, intensity value is different on each pixel. E.g. in the red frame of RGB images intensities values will be high on at these pixels where red color lie in the image. All other pixels values will be less. Similarly in green channel image of a RGB image, pixels values will be higher on the pixels where green color lie in the original RGB image. So by using the intensity value thresholding we can detect the higher intensity value pixels in our image very accurately and in a robust manner. So, after image acquisition we will separate the RGB image into red channel and green channel images by taking the frames from RGB image. We just took these two frames because our points of interest lie in red and green color frames. We will not use blue channel image.

3.3.1 Preprocessing Filtering

After grabbing the frames, now we will apply a noise filter on these frames to remove the noise and to smooth the image. For this purpose we will use median filter (discussed in chapter 2). Median filter will the noise with nicety without preserving the edges and useful information. This filtering will smooth the images and will help to get the more accurate results with less time.

3.3.2 Point Extraction

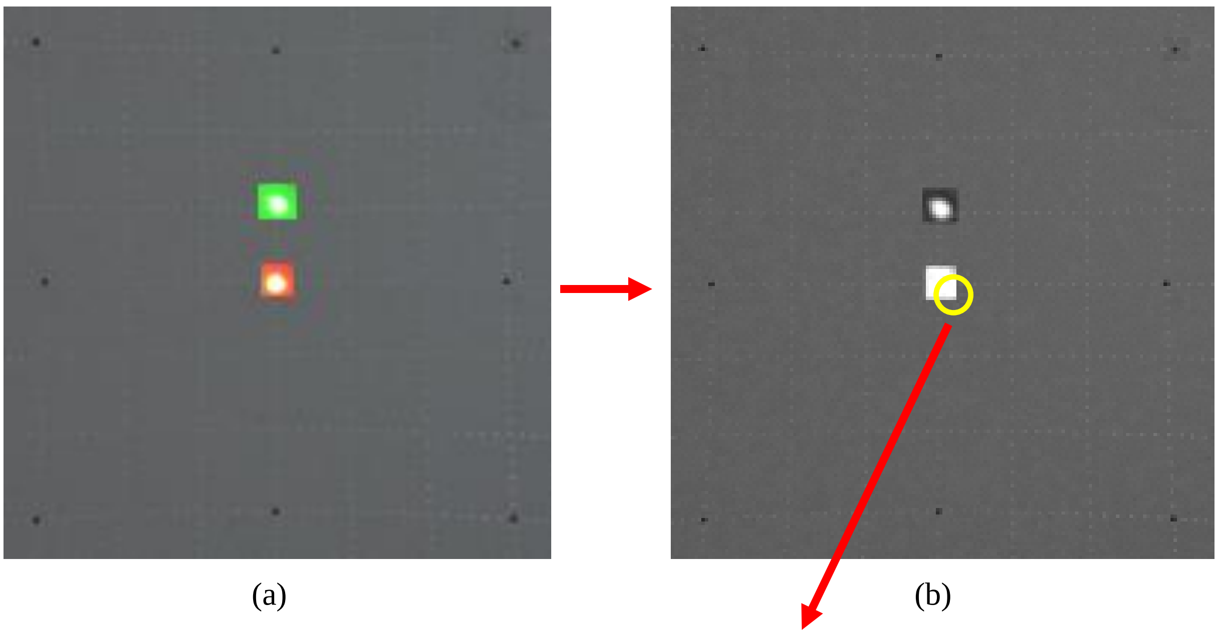
After getting the filtered Red/Green channel images now we will extract the points by using our proposed technique. Figure 3.5 shows the grabbed RGB image and red/green channel images.



(a) (b) (c)

Figure 3.5 Images of Hess Screen a) Grabbed RGB Image b) Red Channel Image c) Green Channel Image.

From image 3.5 we can see in a clear manner that, at the position of red point intensity values are higher and broader in the in the red channel image and similarly at the position of green point, pixels values are higher in the green channel image. In figure 3.6 we can clearly see the intensity value difference at the position of red point in red channel image and vice versa.



(a) (b)

255	255	255	255	255	255	255	255	254	253	251	222	126	105	101	100
255	255	255	255	255	255	255	255	254	253	253	223	127	105	101	101
255	255	255	255	255	255	255	255	253	252	251	224	127	105	101	101
255	255	255	255	255	255	255	255	253	251	251	224	126	105	101	100
255	255	255	255	255	255	255	255	253	250	250	224	126	105	101	99
255	255	255	255	255	255	255	255	253	251	250	224	126	102	99	99
255	255	255	255	255	255	255	255	253	251	250	224	125	100	99	98
255	255	255	255	254	255	254	253	253	252	250	224	125	100	99	98
255	255	255	254	254	255	254	254	253	252	250	224	125	100	99	98
254	255	255	254	254	255	254	254	253	252	250	224	125	100	99	98
254	254	254	254	254	254	254	253	253	252	240	223	125	100	99	98
251	251	252	253	253	253	253	253	253	249	225	205	125	100	99	98
248	248	248	248	248	249	252	252	243	235	208	140	123	100	99	98
240	240	242	242	242	242	240	238	225	208	174	129	110	100	99	98
210	210	210	211	211	211	211	208	205	142	130	118	100	99	98	98
139	140	140	140	140	140	140	140	140	129	115	100	99	98	98	97

Figure 3.6 Intensity values in red channel images a) RGB Image b) Red Channel Image

So, in our proposed technique we used a 5x5 window which will run from the first pixel to the last and at each pixel it will calculate the average of 24 neighbor pixels including the pixel on origin and we will select the pixel with the highest average intensity values as the target pixel.

E.g. in the red channel images where the pixel average intensity value will be the highest that pixel will be consider as the red target point and pixel location of that location will be stored for further processing. Similarly we will find out the green point by using the same technique with the green channel image. Instead of relying on single pixel value we include neighboring pixels which will give more accurate assumption of red or green marks in image.

The algorithm for the red-green point extraction part is below:

Step 1: Divide the input Hess Screen RGB image *I(i,j)* into red channel *I_red(i,j)* and green channel *I_ grn(i,j)* images.

Step 2: Apply the median filter on both red channel images *I_red_filtered(i,j)* and green channel image *I_grn_filtered(i,j)*.

Step 3: Set the maximum intensity value equal to zero.

Step 4: for each pixel of filtered images,

Calculate average intensity value of 5x5 neighboring pixels > maximum intensity value?

If true, store the pixel location as point location.

If false, skip and repeat from step 4.

end_for

Figure 3.7 shows the extraction of red-green points from the acquired RGB image during test by using the purposed technique. This technique can work very accurately in noisy and blurred images as well.

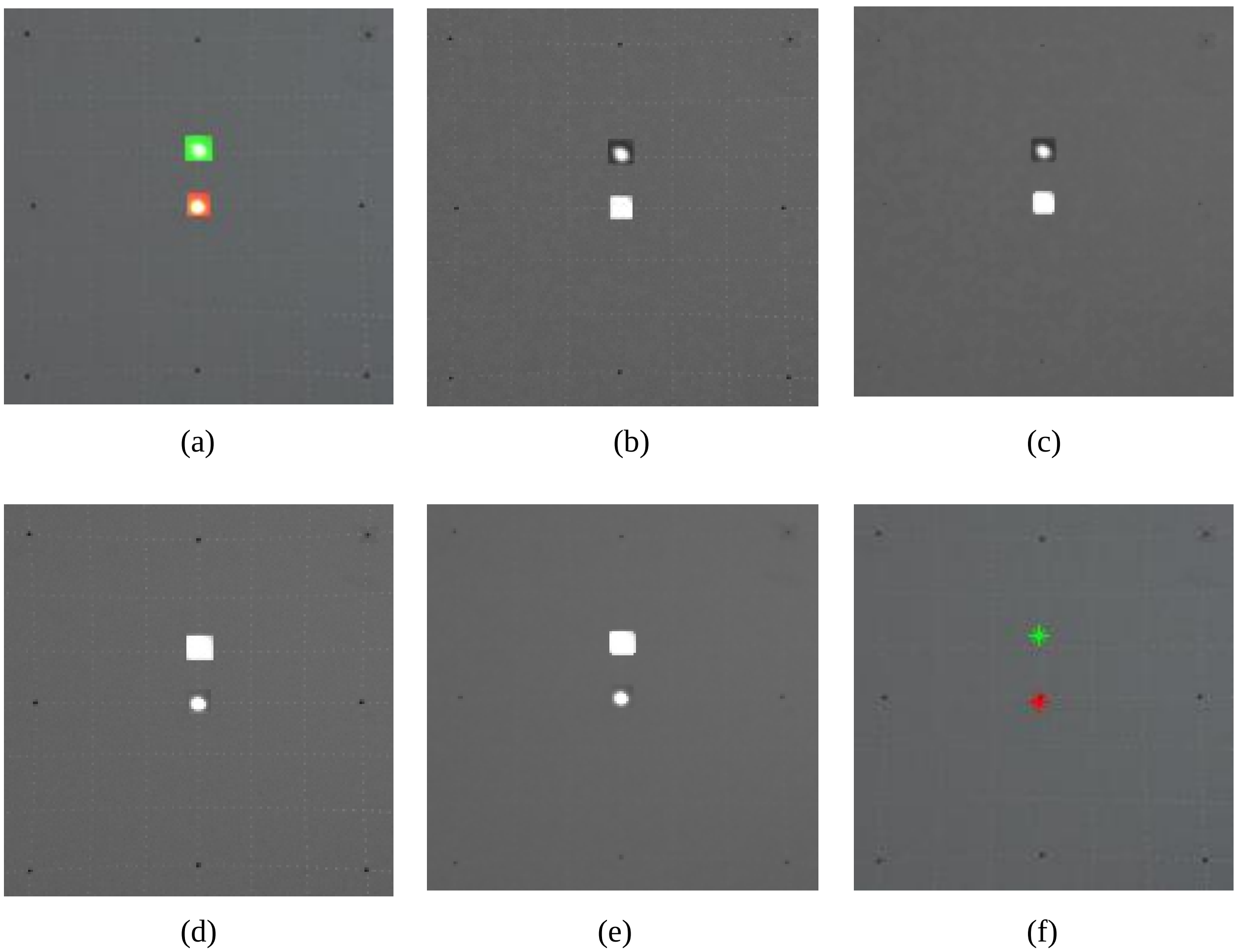


Figure 3.7 Red/Green Point Extraction. a) Color image of Hess board; b) Red channel image; c) Filtered Red channel image; d) Green channel image; e) Filtered Green channel image; f) red/green marks detected

After extracting points from each image we will total have 25 green points and 25 red points for each eye. We will store these points in the computer for further processing.

3.4 Hess Chart Plotting

After extraction of point, we will have total 50 red points and 50 green points for both eyes (25 points for each eye). Now we have to join these points according to medical theory of Hess Screen to make plot for analysis (discussed in chapter 2). According to medical theory of Hess Screen, we will join the 16 points which lie on the outer square in one-to-one formation. This outer square will tell us about the major underacting or overacting of extraocular muscles. After making the outer square, now we will join the inner nine points to make an inner square which further consist of 4 inner smaller squares.

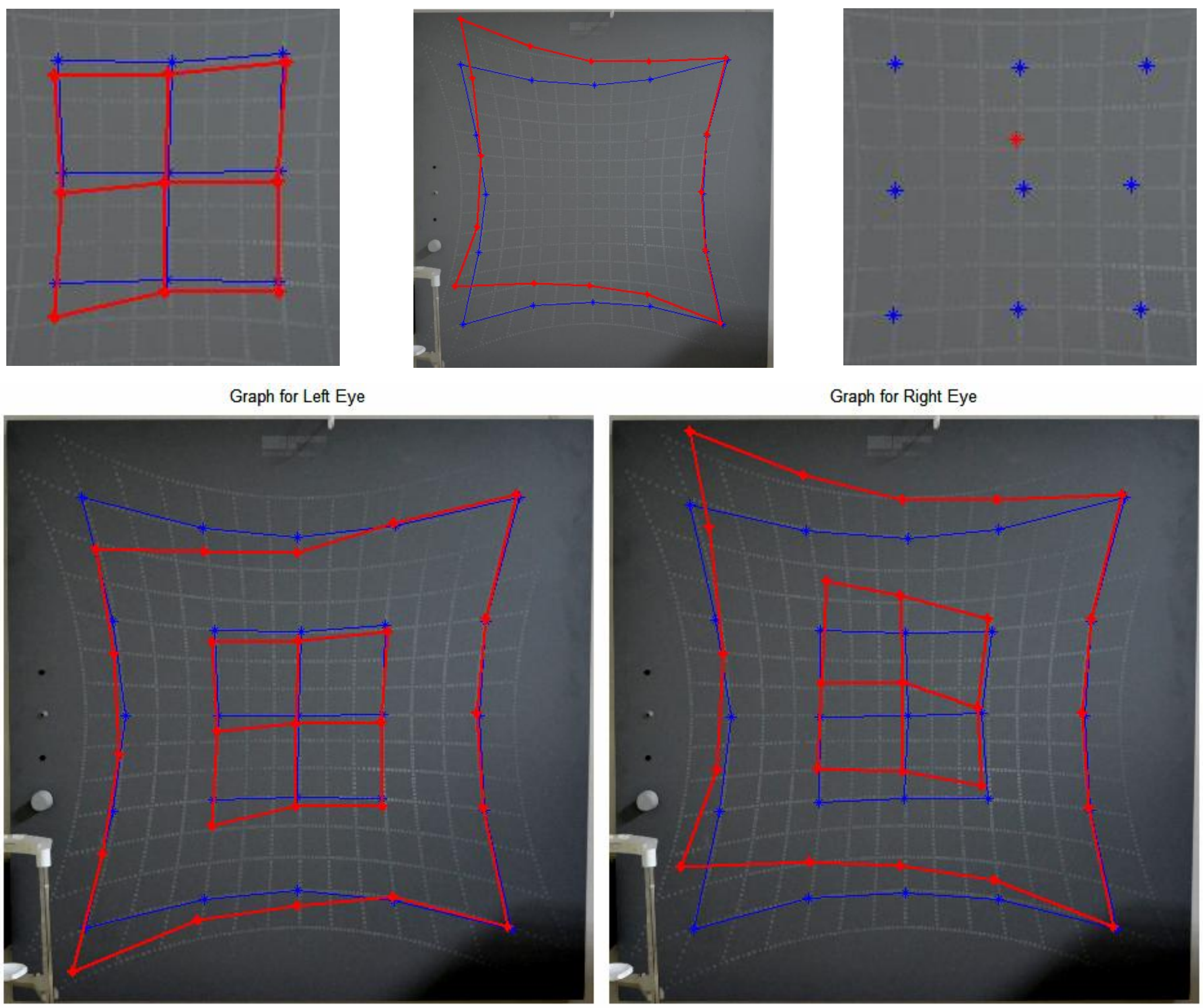


Figure 3.8 Hess Chart Plotting

This inner square is important for diagnosing the diseased eye. Figure 3.8 shows the plotting of inner square, outer square, fixation point and the complete Hess chart by using the stored location of red-green points which were extracted in the last step.

3.5 Automatic Diagnosis System (CAD)

This is the last and most important stage of our proposed model. In this part, we have designed a computer aided diagnosis (CAD) system which will analyze the positions of the points which represents the states of extraocular muscles. On the basis of these analyses we will determine the findings and from these findings we will make our final diagnosis. According to the medical theory of Hess Charting the diagnosis of Hess chart is based on the inner square analysis, fixation spot analysis and outer square analysis. In the end this system will automatically diagnose the type of strabismus based on these analyses.

3.5.1 Inner Square Analysis

In medical theory of Hess chart inner square analysis is very important. Eye with smaller inner square area is considered as diseased eye. So it is very important to calculate the inner square area very accurately. From figure 3.9 we can see that inner square is not in some proper shape like square, triangle, cube sphere or rectangle. So, we cannot apply any straight shape area finding formula on it.

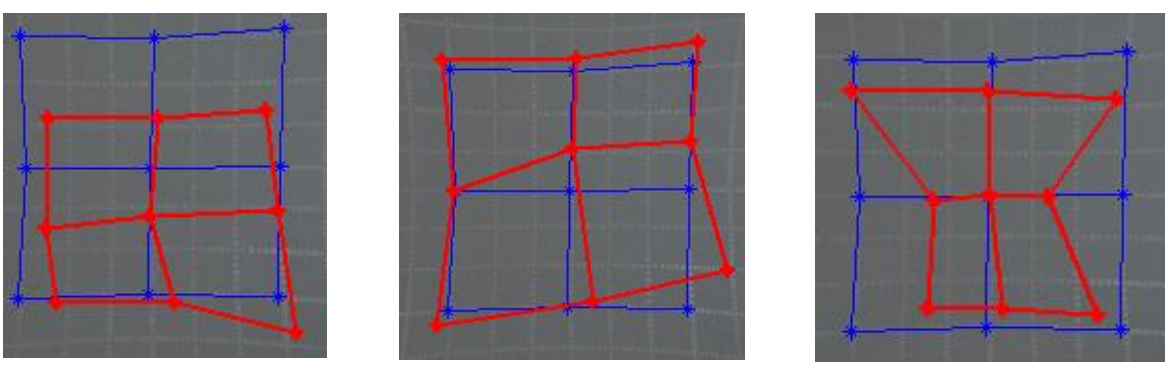


Figure 3.9 Different Shapes of Inner Square.

In our proposed method we implemented an easy and much accurate technique to find the inner square area. In figure 3.9 we can see that inner square is further sub divided into four small squares which are also not in some proper shapes. According to the proposed technique, we divide this smaller inner square into two parts which will convert it into two triangles. We will find the distance from point P1 to P4 of first smaller inner square by using distance formula (Eq. 3.1). Finding this distance *'d'* will divide the small inner square into two parts. Figure 3.10 shows the phenomena of dividing the smaller inner square into two parts and making two triangles.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (3.1)$$

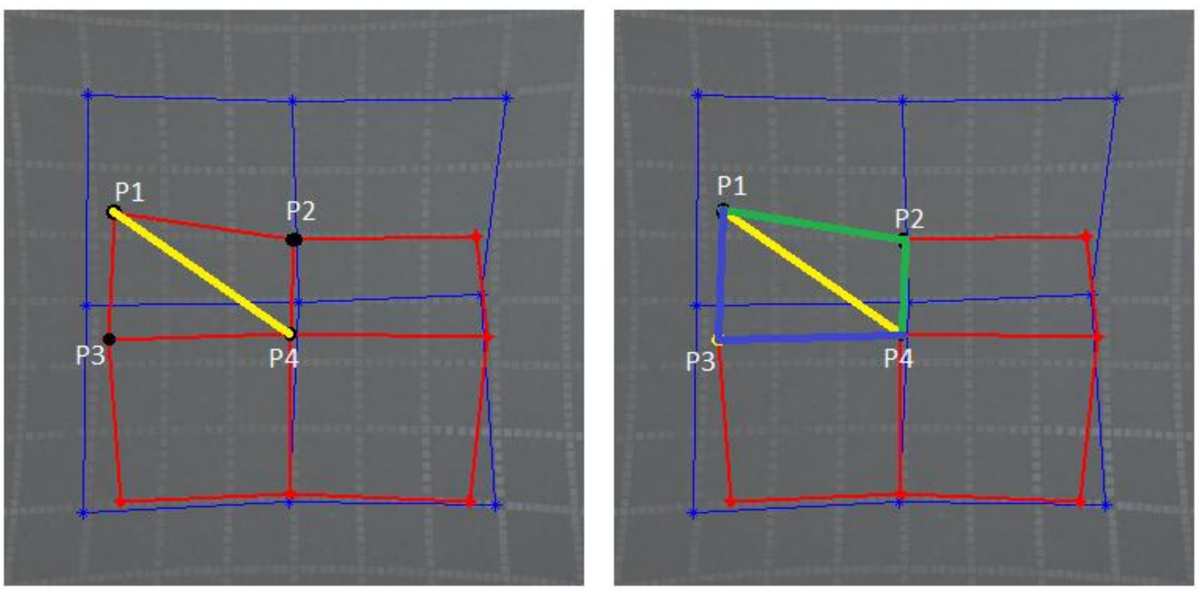


Figure 3.10 Dividing Inner Square into Two Parts.

Now we can clearly see that this small inner square is divided into two triangles. Point P1, P2 and P4 make first triangle and point P1, P3 and P4 makes the second triangle. Now we will find the length of sides off these triangles by using the same distance formula (Eq. 3.1).

After calculating the sides of each triangle now we will find the area of each triangle. For calculating the area we used heron's formula which is defined as:

$$Area_{triangle} = \sqrt{s(s-a)(s-b)(s-c)} \qquad (3.2)$$

Where *'s'* is the semi-perimeter of the triangle and defined as

$$s = \frac{a+b+c}{2}$$

Where a, b and c are the sides of triangle. After calculating the areas of both triangles we will add up these areas to calculate the area of a small inner square. Similarly we will find out the areas of the remaining small inner square. In the end we will add up all the areas of small inner squares and this is how we will get the area of our inner square for analysis. Figure 3.11 illustrate the procedure of making triangles from small inner square and finding the area of inner square.

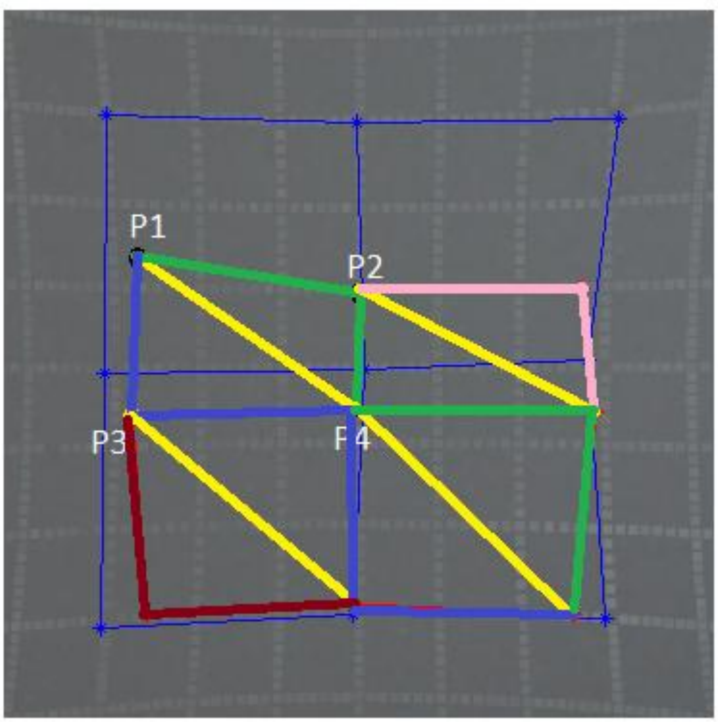


Figure 3.11 Inner Square Analysis procedure.

The algorithm for the Inner square analysis is described below:

Step 1: initialize the "Total Area" as zero

Step 2: for each small inner square '*i'*.

(In our case i=4, because there are four small inner square)

Step 3: assign corner points of small inner square as P1, P2, P3 and P4

Step 4: calculate the distance of sides of triangle "P1-P4, P1-P2, P1-P3, P4-P3 and P4-P2".

Step 5: Find the area of each triangle.

Step 6: Add the area of both triangles to calculate the area of small inner square.

Step 7: Add the area of each small inner square to "Total Area".

end_for

We will find out the area of inner square for both eyes and after calculating the total area of inner square we can easily select the diseased eye by comparing the area of inner square of both eyes. Eye with the smaller inner field will be considered as diseased eye and this information will be stored for further diagnosis.

3.5.2 Fixation Point Analysis

Fixation Point is the most centered point in the Hess Plot. This is also called the primary position of eye. This position is considered as reference point which is at zero degree. In this position none of the muscles is contracted or relaxed. Fixation point analysis is second most important in the diagnosis. Deviation of this spot from origin tells us about the state of tropia (discussed in chapter 2). Zero to five degrees deviation has considered as normal. Five to eight degrees deviation has considered as insignificant and deviation greater than eight degrees has considered as significant.

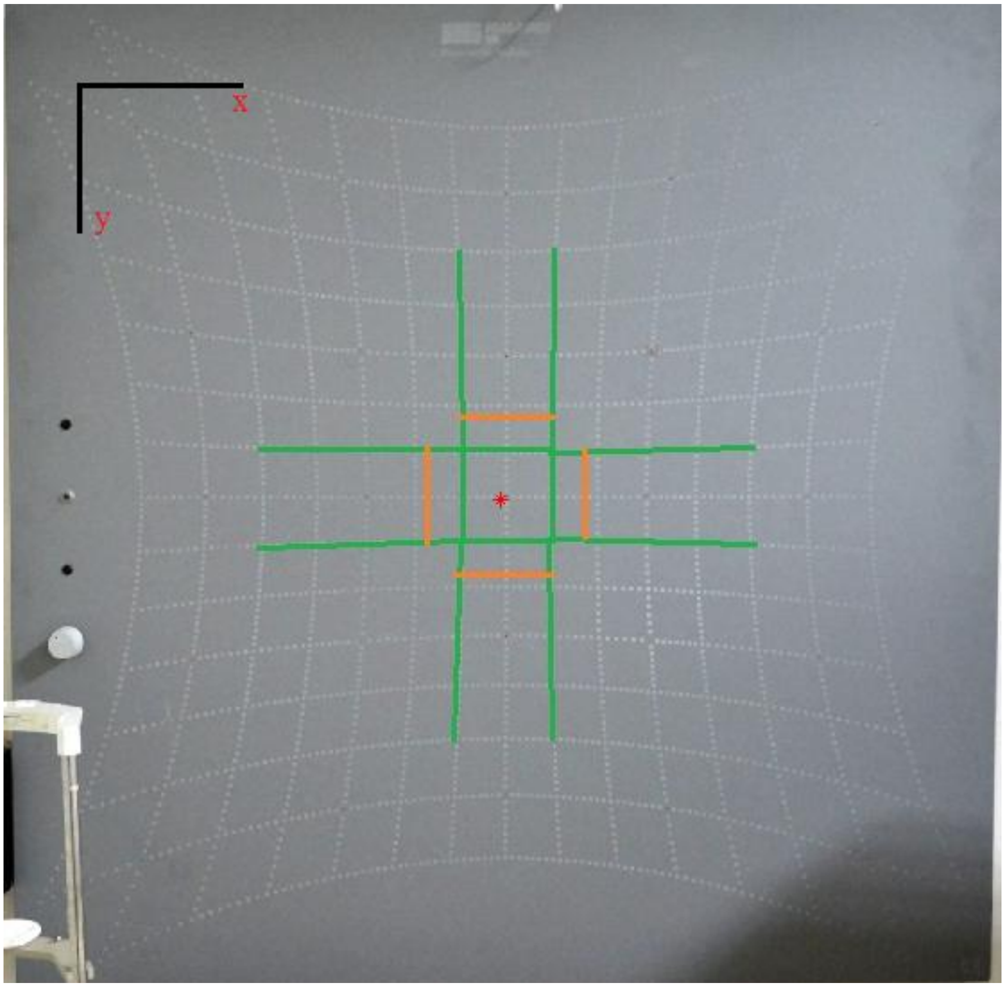


Figure 3.12 Fixation Point Ranges.

Figure 3.12 shows the ranges for fixation point. Red spot which is the fixed centre point will be considered as the origin. In the direction of horizontal axis (x-axis) point within the range of 5^0 upward and 5^0 downward will be consider as normal. Similarly along the vertical axis (y-axis) point within the range of 5^0 on either side will be considered as normal. Normal range is shown by green lines in the figurer 3.12. Insignificant range which lies between 5^0-8^0 is shown by orange lines. Any fixation point beyond these limits will be considered as significant deviated point.

In this system we have calculated the distance of fixation point from the origin in x-y axis direction. For finding the distance we will subtract the patient projected centre point which is variable with the fixed centre point. Direction of the distance is very important as it told us about the type of tropia. If deviation of centre point is in the negative direction of y-axis (Superiorly) then it is hypertropia and if deviation is in the positive direction of y-axis (Inferiorly) then it is hypotropia. For the right eye if the distance is in the negative direction of x-axis (Nasally) then it is esotropia and if distance is in the positive direction of y-axis (Temporally) then it is exotropia and for the left eye distance directions will be changed positive distance along x-axis will show esotropia and negative distance will show exotropia. In some cases, fixation point crosses the normal limit of both vertical and horizontal planes in that case we will announce it as the both type of tropia according to direction. We will convert distance into degree of deviation for further processing. E.g. for each degree of deviation there must a distance difference of 13 from the origin point. So for 5^0 there must be a distance of equal to 66 and vice versa.

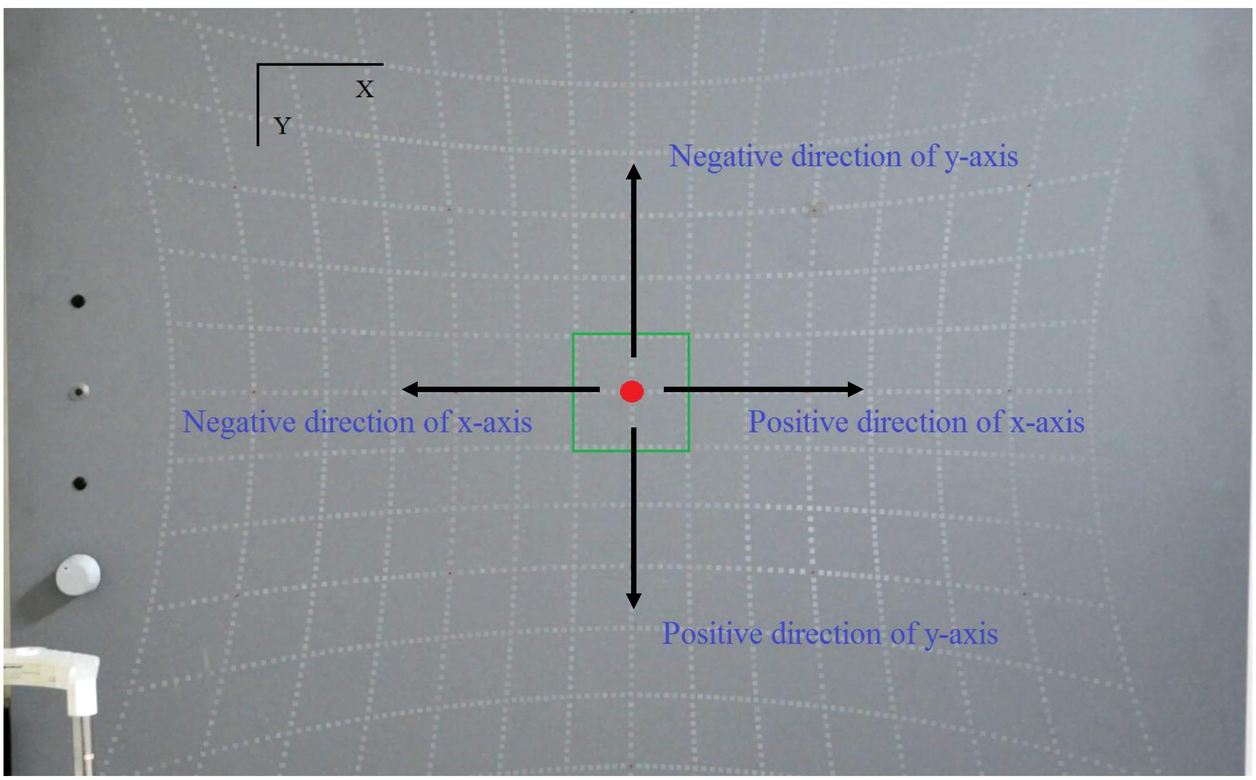


Figure 3.13 Direction of Deviation of Fixation Point.

We have used Fuzzy Logic technique in this part of diagnosis system. We will calculate the distance of variable patient point with the fixed centre point and will give this distance to the fuzzifier. Here, fuzzifier will describe the distance value according to the membership function in some fuzzy linguistic variable. Figure 3.14 shows the membership function for centre point analysis.

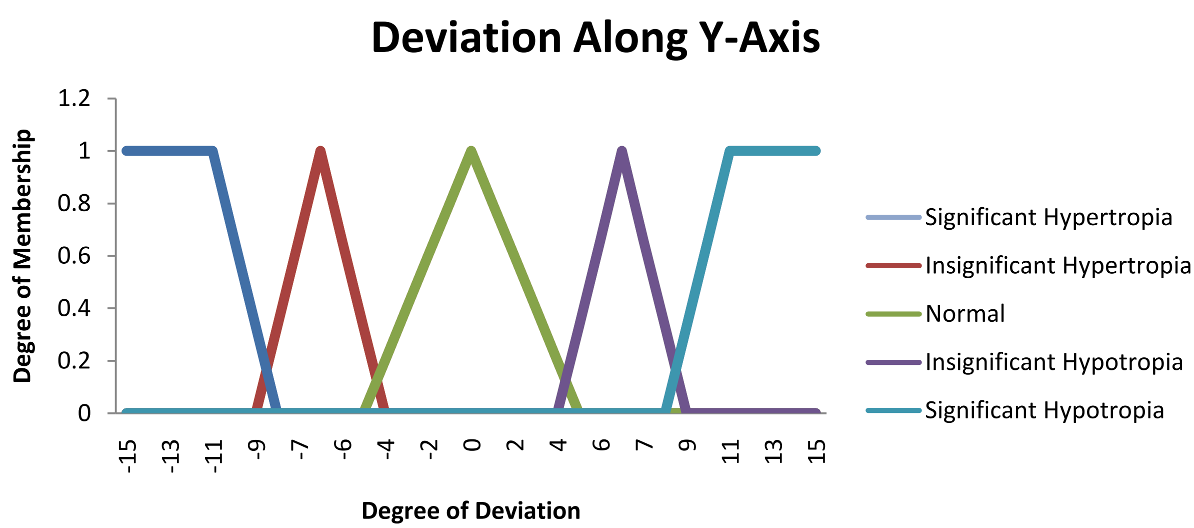


Figure 3.14 Membership For Deviation along Y-Axis

From this membership function we can observe that, if the centre point is deviated superiorly (in negative degree of deviation) then it will check according to this function that in which category it lies. According to that category it will assign the state and type of tropia. E.g. if our point is 9^0 deviated in then it will assign the state as significant and according to positive direction it will assign the type of tropia as hypotropia. Similarly, if the point is -7^0 then this function will assign the state as insignificant and type as hypertropia.

Similarly we have designed the membership function for the deviation in the x-axis. But these membership functions will be different for the both eye. For the right eye, deviation in the negative direction of x-axis is consider as esotropia but for the left eye it would be consider as exotropia. So we have to define separate function for both eyes. The membership function schematic for right eye deviation in x-axis can be seen in figure 3.15.

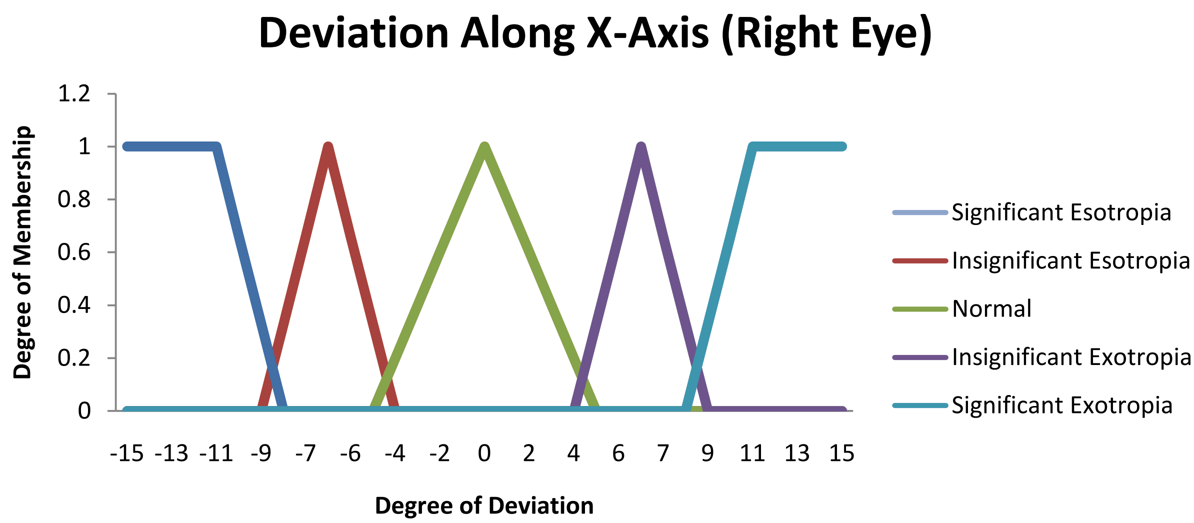


Figure 3.15 Membership For Deviation along X-Axis (Right Eye)

The membership function schematic for left eye deviation in x-axis can be seen in figure 3.16

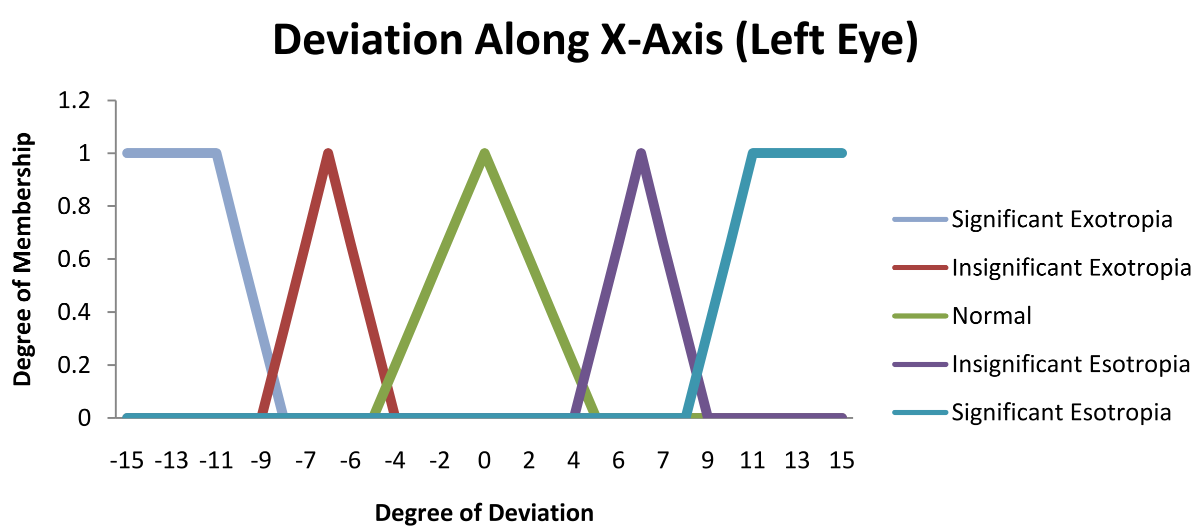


Figure 3.16 Membership For Deviation along X-Axis (Left Eye)

Along with the deviation of centre point we also check the deviation of points on elevation, depression, levoversion and dextroversion. These point also deviate w.r.t fixation point. We have to check that either these points moves the same distance as fixation point did or not. E.g. if there is significant hypertropia is present then we will check levoversion and dextroversion point. If the movement of these points is same then we will say that hypertropia remains same on levoversion and dextroversion. If levoversion point advances in distance w.r.t fixation point then we will say that hypertropia detected which increases on levoversion. Similarly we have to check elevation and depression point when there is exotropia or esotropia is present.

After getting the type and state of tropia information using these membership functions now we will apply inference rules on these inputs to make the final decision about our fixation point analysis. Inference rules take side of eye, type of tropia, state of tropia, position of elevator of depressor points or levoversion of dextroversion point as input and according to combination of these inputs it will display the diagnosis result as output. Following are the examples of rules which we have implemented for this diagnosis system.

Normal Rule:

$$
\begin{aligned}
&IF\ (eye == right)\ AND\ (type == none)\ AND\ (state == normal)\ldots\\
&THEN\ command\ is\ 'Fixation\ point\ is\ normal\ in\ position'
\end{aligned}
$$

This normal will apply when fixation point will be in the normal range from all sides.

Hypertropia Rule:

$$
\begin{aligned}
&IF\ (eye == right)\ AND\ (type == hypertropia)\ AND\ (state == insignificant)\ldots\\
&AND(levoversion\_position == increasing)AND(dextroversion\_position == normal)\\
&THEN\ command\ is\ 'Insignificant\ Right\ Hypertropia\ldots\\
&which\ Increases\ on\ Levoversion\ but\ remain\ normal\ on\ Dextroversion'
\end{aligned}
$$

In hypertropia, there will be three rules defininining state of tropia, with the combination of nine subrules which defines the levoversion and dextroversion position. We will have separate rules for right and left eye.

Hypotropia Rule:

$$IF\ (eye == right)\ AND\ (type == hypotropia)\ AND\ (state == significant)....$$
$$AND(levoversion\_position == increa\sin g)AND(dextroversion\_position == increa\sin g)$$
$$THEN\ command\ is\ 'significant\ Right\ Hypotropia...$$
$$which\ Increases\ on\ both\ Levoversion\ and\ Dextroversion'$$

Similarly we will have 3 main rules and combination of 9 sub rules defining the position on levoversiona nd dextroversion.

Esotropia Rules:

$$IF\ (eye == left)\ AND\ (type == esotropia)\ AND\ (state == significant)....$$
$$AND(elevator\_position == increa\sin g)AND(depressor\_position == decrea\sin g)$$
$$THEN\ command\ is\ 'significant\ Left\ Esotropia...$$
$$which\ Increases\ on\ Elevation\ and\ decreases\ on\ Depression'$$

In the esotropia we will have separate rules for left and right eyes. In this case we will also have 3 main rules defining state of esotropia and 9 subrules for each main rule which will tell us about the elevator and depressor postion w.r.t fixation point.

Exotropia Rules:

$$IF\ (eye == right)\ AND\ (type == exotropia \,\&\, hypertropia)....$$
$$THEN\ command\ is\ 'Both\ Exotropia\ and\ Hypertropia\ \det ected\ in\ Right\ eye'$$

Similarly, in the exotropia we will have separate rules for left and right eyes. In this case we will also have 3 main rules defining state of exotropia and 9 subrules for each main rule which will tell us about the elevator and depressor postion w.r.t fixation point.

Complex Case Rules:

$$IF\ (eye == right)\ AND\ (type == exotropia\ \&\ hypertropia)....$$
$$THEN\ command\ is\ '\ Both\ Exotropia\ and\ Hypertropia\ \mathrm{det}\ ected\ in\ Right\ eye\ '$$

This rule will be called when fixation point will be out of normal range in both axis. We will have total 4 rules for each eye.

The alogirhtm for the fixation point analysis is described below:

Step 1: Take the variable (patient/green) centre point and fixed (red) centre point and subtract green point from the fixed red point to get the distance *'d'.*

Step 2: Take distance '*d'* as the input to fzzifier and allot the state & type of tropia membership according to the membership function.

Step 3: for each plot of a case apply the inference rules on the input
(Input = 'output of membership function' , 'supporting muscles positions')

If true, detect the disease according to the rule and display.
if false, mark the disese as complex.

end_for

Figure 3.17 shows the results based on our proposed technique for the fixation point analysis. By using this rule based approach we have developed a generic diagnosis algorithm which can detect any type of disease related to fixation point. In the following image we can observe that this algorithm detected the disease very accurately and with nicety.

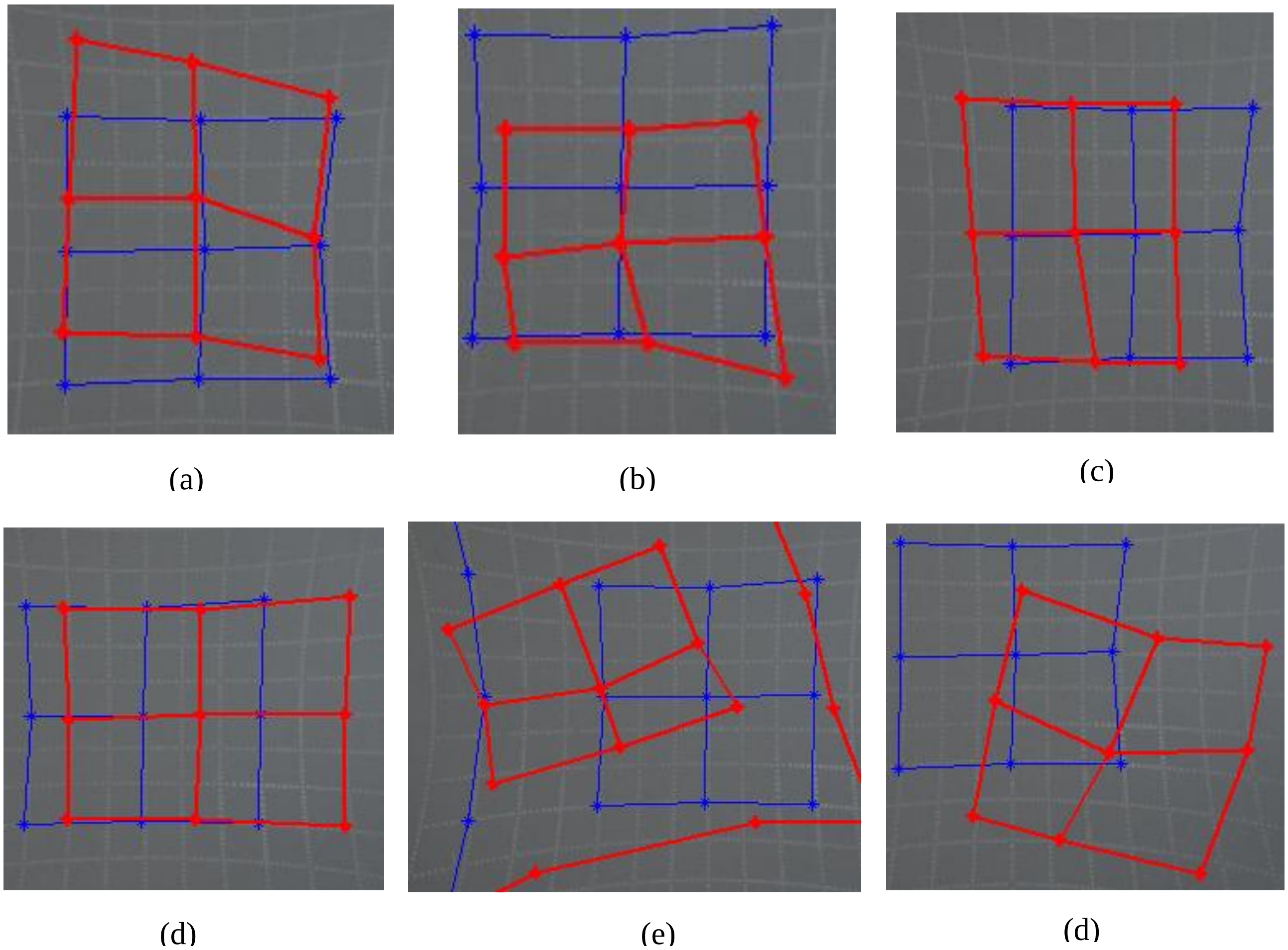


Figure 3.17 Fixation Point Analysis a) Right Hypertropia b) Left Hypotropia c) Right Esotropia d) Left Esotropia e) Left Exotropia d) Complex case with both right hypotropia and esotropia.

3.5.3 Outer Square Analysis

Outer Square is situated at thirty degree from the origin (fixation point). Outer square analysis is important for analyzing that which type of disease is present in the eye. By analyzing the position and combination of the points of outer square we have to diagnose the type of disease as paralytic strabismus or restriction. In this analysis we have to analyze the states of muscles as normal, underacting or overacting. In the outer square there are total 16 points out of which 6 points are important. These points represent the states of 6 extraocular muscles of eye. Out of these 6 important points, four corner points of outer square will represent the four vertical plane extraocular muscles (Inferior Rectus, Inferior Oblique, Superior rectus and Superior Oblique) and middle points of right and left side of square line represent the horizontal plane extraocular muscles (Medial Rectus and Lateral Rectus). We will consider only these six points from outer square. Same six points of inner square also represent these muscles position. So we will also consider the deviation of these points in the outer square analysis. Figure 3.18 shows the points of consideration on inner square and outer square. Red dots show the points of interest on outer square and yellow dots shows the points of interest in inner square. Green point shows the fixation point.

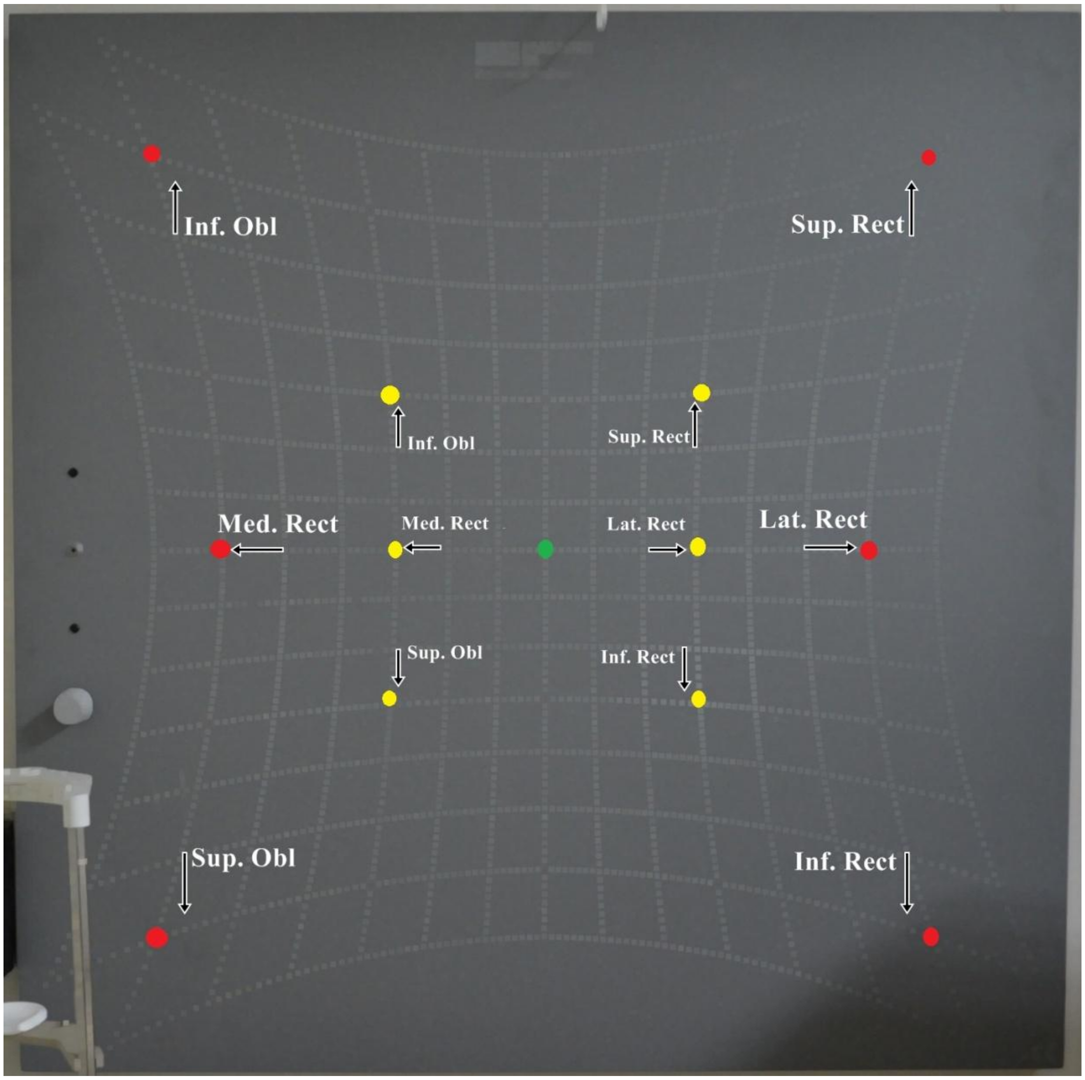


Figure 3.18 Muscles Point at Inner Square and Outer Square.

As we have discussed in chapter two that, here are three nerves associated with these muscles for nerve supply. Lateral Rectus got its nerve supply from VI Abducens nerve; Superior Oblique got its nerve supply from IV Trochlear nerve and all other muscles Superior rectus, Inferior rectus, Medial rectus and Inferior oblique got their nerve supply from III oculomotor nerve. So, any problem in the muscles could be due to some problem in these nerves of or because of some mechanical faults in muscles or orbit which is generally known as trauma cases.

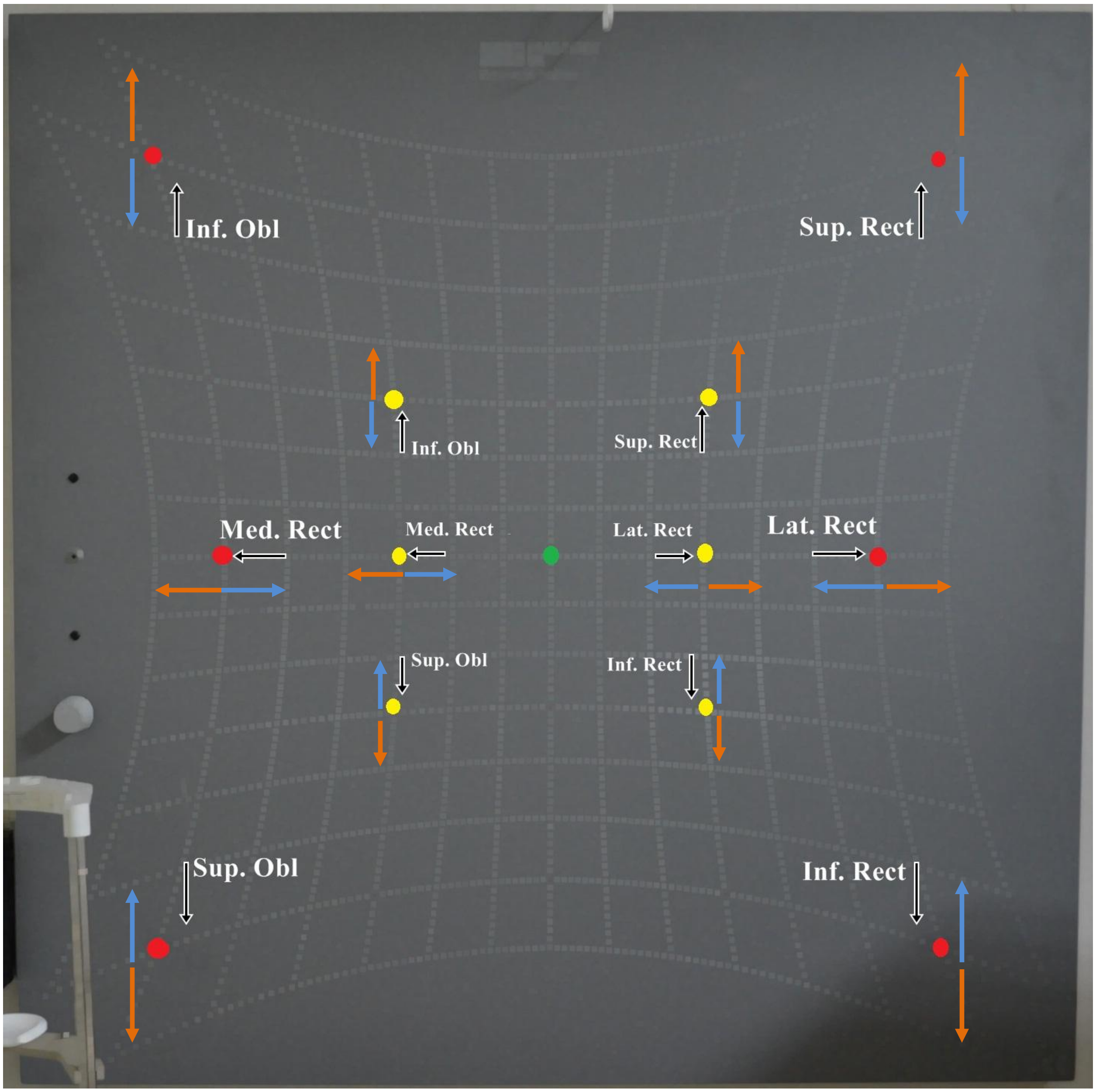


Figure 3.19 Normal, Overacting and Underacting Ranges.

In the outer square analysis, we have to calculate the distance of each muscle point from their reference (fixed) point and according to distance we have to define that muscle state as normal, underacting, or overacting. 5^0 displacements to the both side from the reference point has to be considered as normal, displacement greater (towards outside) than $+5^0$ degree has to be considered has overacting and displacement shorter (towards inside) than -5^0 degree has to be considered as underacting. Figure 3.19 shows the range and direction of underacting and overacting of muscles. Brown arrows show the direction of overacting of muscles and blue arrow shows the underacting direction. Arrows tip shows the normal range of the point deviation. If some point deviates beyond these limits which are shown by arrow tip then it will not consider as normal.

Our system of outer square analysis system is also based on Fuzzy Logic. In this system we have to calculate the muscles states of both eyes. To calculate the muscles states we will take both variables (patient's) point and fixed (red) points and find the difference of these points. After finding the distance we will give this distance to the fuzzifier of our outer square analysis system. According to the membership function, fuzzifier assign the muscles state. Membership function schematic can be seen in the figure 3.20 given below.

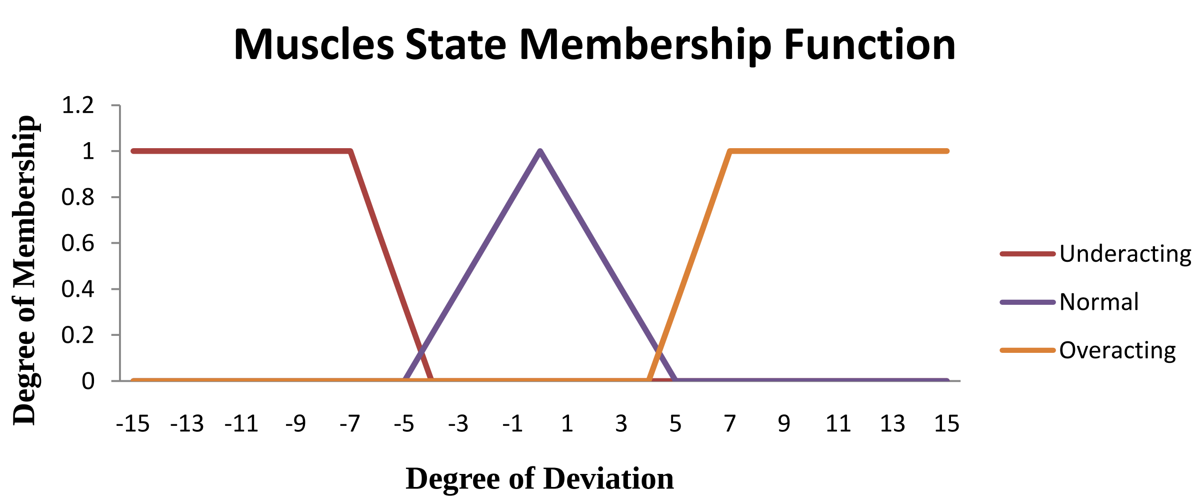


Figure 3.20 Muscles state Membership Function.

According to this membership function, point which will lie between the ranges of -5^0 to $+5^0$ will be considered as normal. Any point below -5^0 ranges will be regarded as underacting and point above $+5^0$ will be considered as overacting. Here normal, underacting and overacting are the fuzzy linguistic variables which we are assigning according to the input.

After assigning the muscles state now we will apply the inference rules on these inputs. The inference rules have been designed according to the medical theory of Hess Chart. In these rules, we analyze the different muscles states with different combinations to diagnose the disease. These rules differ according to the nature of the disease. Following are the examples of rules along with their details.

3.5.3.1 Nerve Palsy Cases:

According to the medical theory of Hess Screen, first of all we have to check that which eye is the diseased eye. We can detect the disease eye by simply finding the inner square area and comparing them. Eye with the smaller area will be considered as diseased eye. We have discussed this step in inner square analysis. After finding the diseased eye, we will find the state of each muscle according to the membership function. Now, for the Palsy cases we have to check the different combination of the muscles states in both eyes. These combinations are different for the different nerves palsies. Each of nerve palsy rule is discussed below.

I. **Lateral Rectus (CN VI) Palsy:**

As we know that LR gets its supply from sixth CN. So, lateral rectus palsy is also known as sixth cranial nerve palsy. According to medical theory of Hess Screen, first of all we have to check the major underacting muscle in the diseased eye. For sixth nerve palsy major underacting muscle should be LR of diseased eye. After checking the major underacting then we have to check the muscle state of direct agonist muscle. Direct agonist for the LR is the MR of the same eye. This direct agonist should be overacting in state. Now in the other eye we have to check the position of the contralateral synergist and contralateral antagonist muscles. MR of other eye is the contralateral synergist of LR diseased eye and it should be in overacting state and LR of other eye is the contralateral antagonist of the LR of the diseased eye and it should be underacting.

Any case fulfilling this rule criterion will be diagnosed as Sixth Nerve Lateral Rectus Palsy. Following is the rules example for LR palsy.

$$\begin{aligned}
&IF\ (major_underacting == right_LR)\ AND\ (right_MR == overacting)...\\
&AND\ (left_MR == overacting)\ AND (left_LR == underacting)...\\
&THEN\ command\ is\ 'Right\ Lateral\ \mathrm{Re}\,ctus\ (VI\ Nerve)\ Palsy'
\end{aligned}$$

Figure 3.21 shows the right LR (VI nerve) palsy detected in Hess Chart.

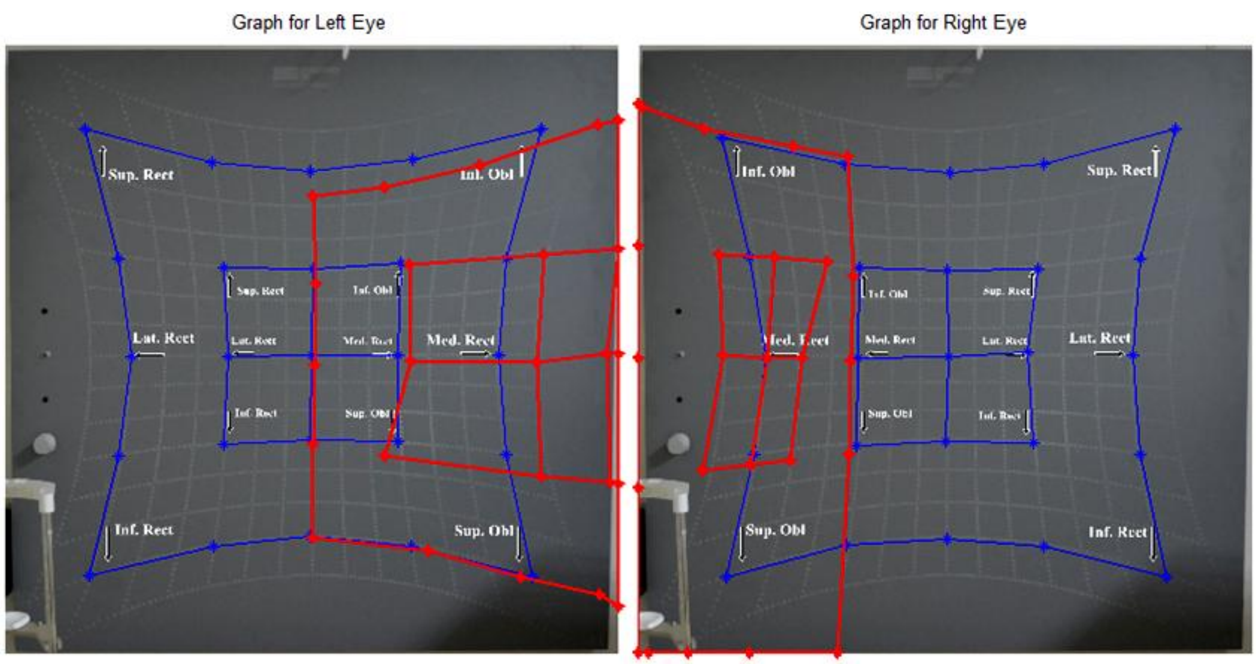


Figure 3.21 Right Lateral Rectus (VI nerve) Palsy Hess Chart.

II. **Superior Oblique (CN IV) Palsy:**

SO muscles got its nerve supply form the fourth cranial nerve. For this nerve palsy major underacting muscle should be SO of diseased eye and direct agonist IO of the same eye should be overacting. In the other eye contralateral synergist IR should be overacting and contralateral antagonist SR should be underacting. Following rules implementation shows the detection of SO (IV nerve) palsy.

$$IF\ (major\_underacting == right\_SO) AND (right\_IO == overacting)...$$
$$AND (left\_IR == overacting) AND (left\_SR == underacting)...$$
$$THEN\ command\ is\ 'Right\ Superior\ Oblique\ (IV\ Nerve)\ Palsy'$$

Figure 3.22 shows the left SO palsy in Hess Chart.

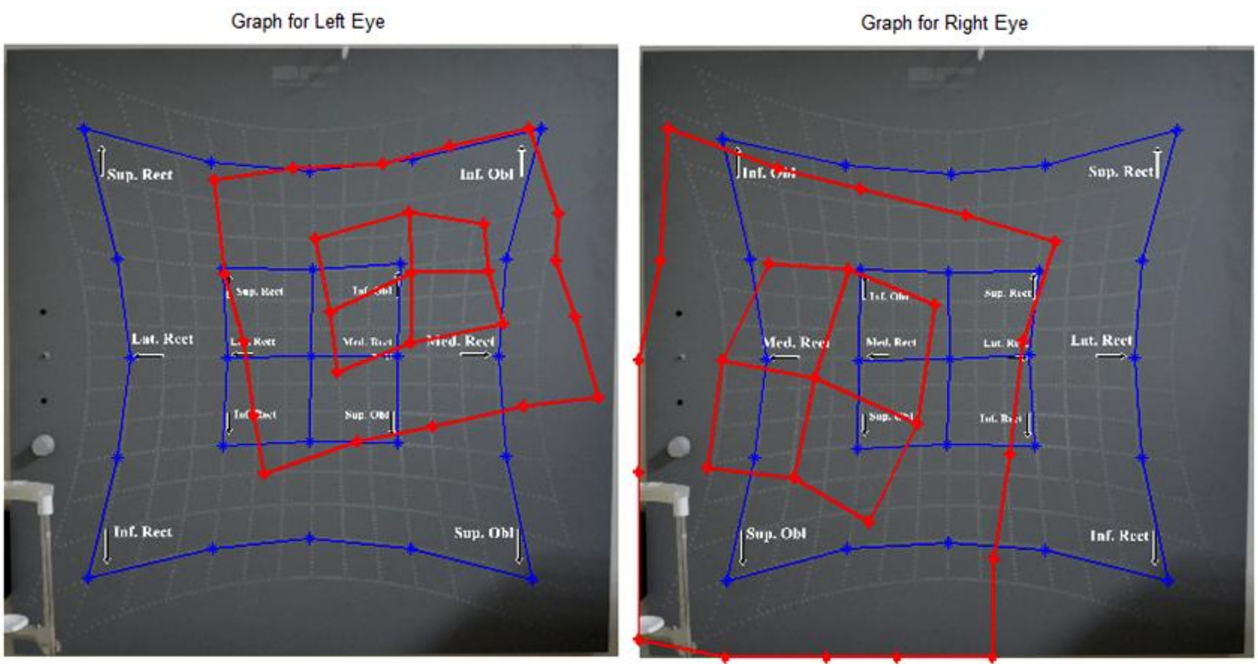


Figure 3.22 Left SO (IV Nerve) Palsy Hess Chart.

III. **III Nerve Palsy:**

There are four muscles which got their nerve supply from III nerve. III nerve is associated with MR, SR, IR and IO muscles. There are two possibilities of III nerve palsy. One is complete III nerve palsy and second is partial III nerve palsy. In complete III nerve palsy, all muscles associated with the III nerve will be in underacting state and contralateral synergist of each muscle must be in overacting state. Following rule implementation shows the diagnosis of complete III nerve palsy.

$$IF\ (left\_IR == underacting)\ AND\ (left\_SR == underacting)...$$
$$AND\ (left\_IO == underacting)\ AND (left\_MR == underacting)...$$
$$THEN\ command\ is\ 'Left\ Complete\ III\ Nerve Palsy'$$

Figure 3.23 shows the left complete III nerve palsy.

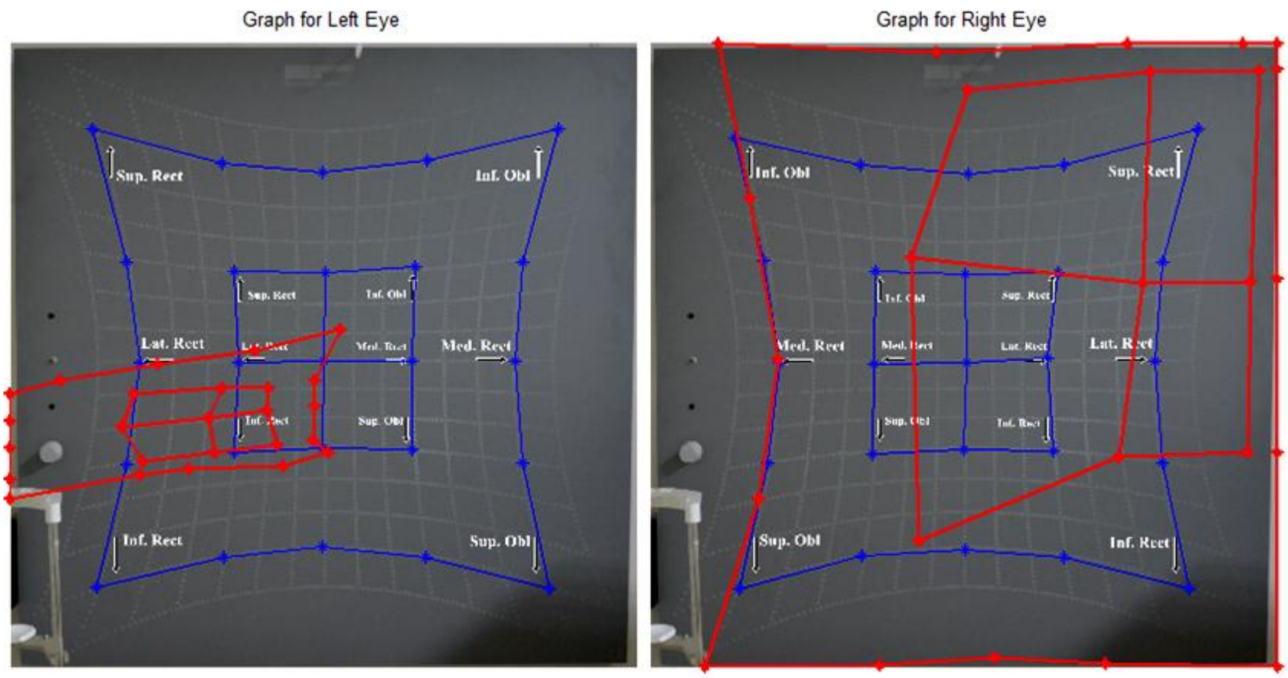


Figure 3.23 Left Complete III Nerve Palsy.

Partial III nerve palsy is very rare to be found in any patient. To check the partial III nerve palsy we have to apply the same rule of muscles combination for each muscle. E.g. for MR (III nerve palsy) MR should be major underacting muscle and its direct antagonist LR should be overacting and its contralateral synergist LR of other eye should be overacting and its contralateral antagonist should be underacting. Similarly we have to apply this combination of muscles state for other muscles associated with III nerve supply.

3.5.3.2 Restriction Cases:

If muscles of one complete side or both side of an eye are restricted in underacting state then these are known as restriction cases. There are two planes in the movement of the eyes. One is horizontal plane which includes the LR and MR muscles. If both LR and MR muscles are in underacting state then it could be a case of restriction in horizontal plane. It is very rare to find the horizontal plane restriction in the patients. Second plane is vertical plane. This plane includes IO, SO, IR and SR muscles. SR and IO muscles are known as orbital roof muscles. IR and SO are known as the orbital floor muscles.

If SR and IO muscles state are underacting then we will diagnose the restriction in the orbital floor of that eye. This is because floor muscles must be trapped somewhere and not letting the eye ball to go up. Similarly if the IR and SO muscles are underacting then we should diagnose it with the orbital roof restriction, because roof muscles are not letting the eye ball to go down because of trapped pathology.

If both roof and floor muscles are in underacting state then it should be diagnose as the restriction in the complete vertical plane of that eye. Following are some rules implementation for restriction cases.

Right vertical plane restriction case:

IF(right_IO == underacting) AND (right_SO == underacting)...
AND(right_SR == underacting) AND (right_IR == underacting)...
AND(left_IO == overacting) AND (left_SO == overacting)...
AND(left_SR == overacting) AND (leftlt_IR == overacting).
THEN command is 'Right Orbit Vertical Plane Restriction'

Orbital Floor Restriction Rule:

IF(right_SO == underacting) AND (right_IR == underacting)...
AND(right_SR == overacting) AND (right_IO == overacting)...
THEN command is 'Restriction in Left Orbital Floor'

Figure 3.24 shows the Hess chart of left vertical plane restriction.

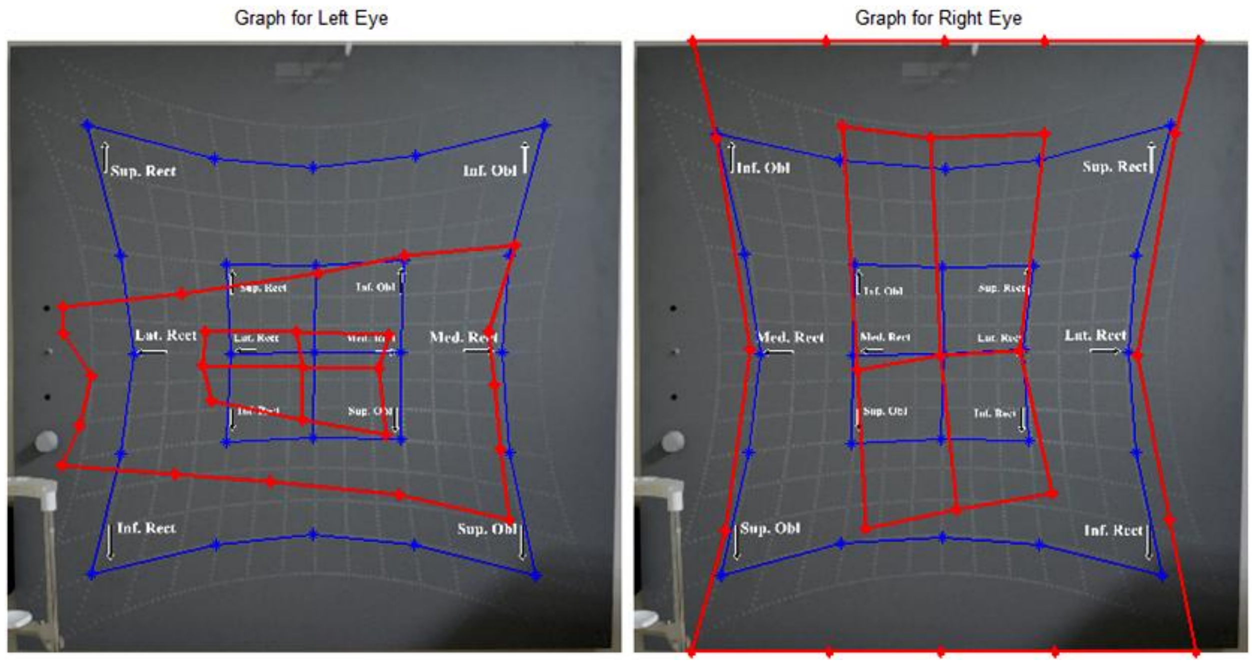


Figure 3.24 Left Vertical Plane Restriction Hess Chart.

Figure 3.25 shows the left orbital floor restriction Hess chart.

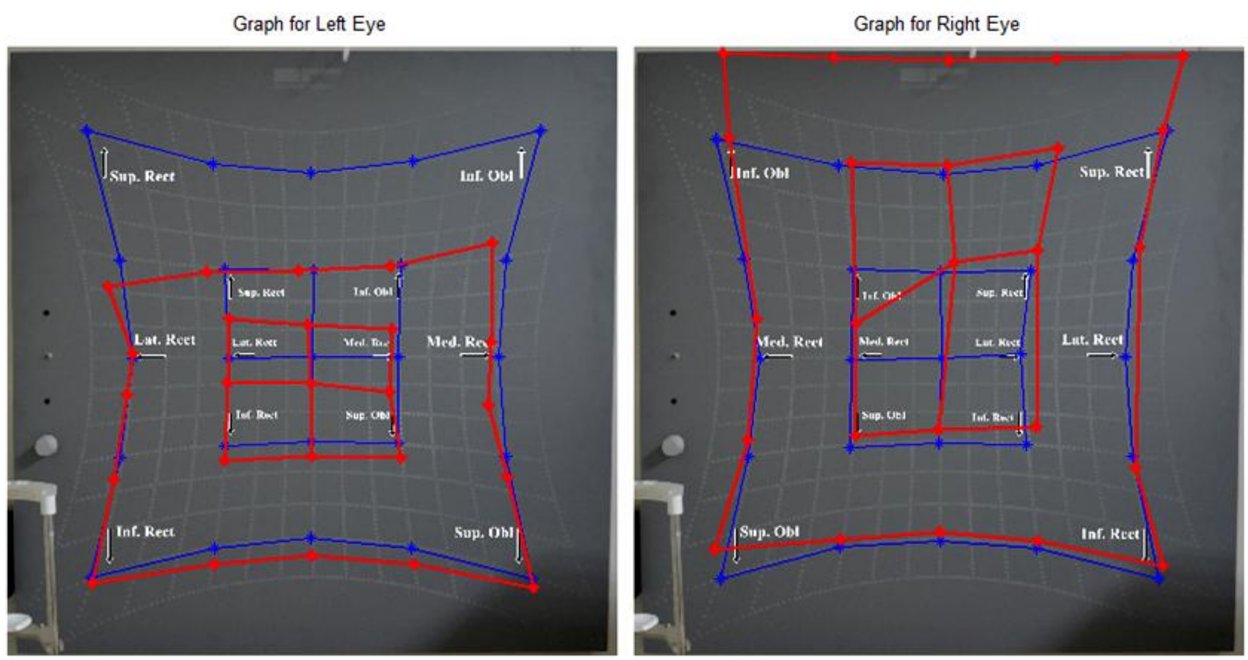


Figure 3.25 Left Orbital Floor Restriction Hess Chart.

Orbital Roof Restriction:

$$\text{IF(right\_SO == underacting) AND (right\_IR == underacting)...}$$
$$\text{AND(left\_SO == overacting) AND (left\_IR == overacting)...}$$
$$\textit{THEN command is}\ \text{'Re}\,\textit{striction in Right Orbital Roof}\ \text{'}$$

Figure 3.26 shows the right orbital roof restriction Hess chart.

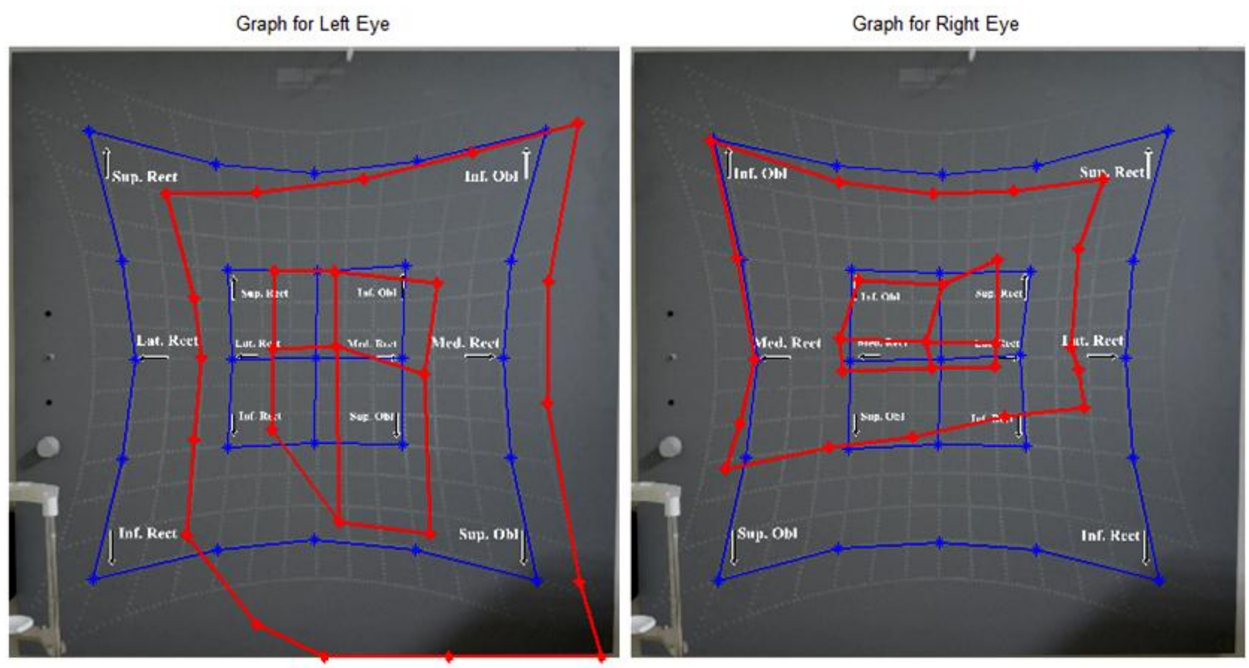


Figure 3.26 Right Orbital Roog Restriction Hess Chart.

The process of outer square analysis described in the algorithm below:

Step 1: take the corresponding muscles point as input

Step 2: find the distance of each point from their fixed point

Step 3: give this distance to the fuzzifier which will assign the state according to the membership function

Step 4: **for** the diseased eye

Step 5: find major underacting muscle

Step 6: Apply inference rules

If_true, diagnose the disease according to rule

If_false, display clinical correlation advise

end_for

3.6 Summary

Automated system of Hess Screen for diagnosis of paralytic strabismus is consist of image acquisition, red-green point extraction, preprocessing of red-green channel images, Hess chart plotting and automated CAD algorithm. In the image acquisition step we acquire the Hess screen image and split it into red and green channel image. We apply median filter in preprocessing step for noise removal. Then we applied a moving average window technique on the green and red channel images to extract the location of the red-green points. After point extraction, according to the medical theory of Hess Screen we plot the Hess Chart for the visual inspection of the disease. Automated diagnosis algorithm is based on three analyses. One is inner square analysis which is done by finding the area of inner square of both graph and graph with the small area has to be considered as diseased eye. Second analysis is fixation point analysis, which is used to find the type and state of tropia in the eyes. Third and most important analysis is outer square analysis which tells us about the type of disease present in the diseased eye. We have use fuzzy logic approach for analysis of fixation point and outer square.

Chapter 4: Results and Discussion

In this chapter, we have discusses the results of implementation of automated system of Hess screen for diagnosis of paralytic strabismus. These results include the brief discussion about dataset acquired for testing, implementation results of automated system, and discussion on these results. We have used the following parameters to compare the results of automated system.

1. Visual Inspection
2. Accuracy

4.1 Dataset

Evaluation of automated system of Hess screen was very important and has been done very carefully. To test this automated system it was compulsory to get some high quality and reliable dataset. With the affiliation of Armed Forces Institute of Ophthalmology, (AFIO) Rawalpindi, we got complete medical knowledge and background about the Hess screen theory and strabismus.

For acquiring data set for experiment, we take the images of Hess screen during test at AFIO by using a simple digital USB camera. We acquired total 25 test cases images. We have conducted our experiments using these datasets. This data set was firstly verified by specialist and then we have used this in our automated system for evaluation.

Following are some images taken during the test and which we have used as dataset.

Figure 4.1 Data Set Images of Hess Screen

4.2 Experimental Results

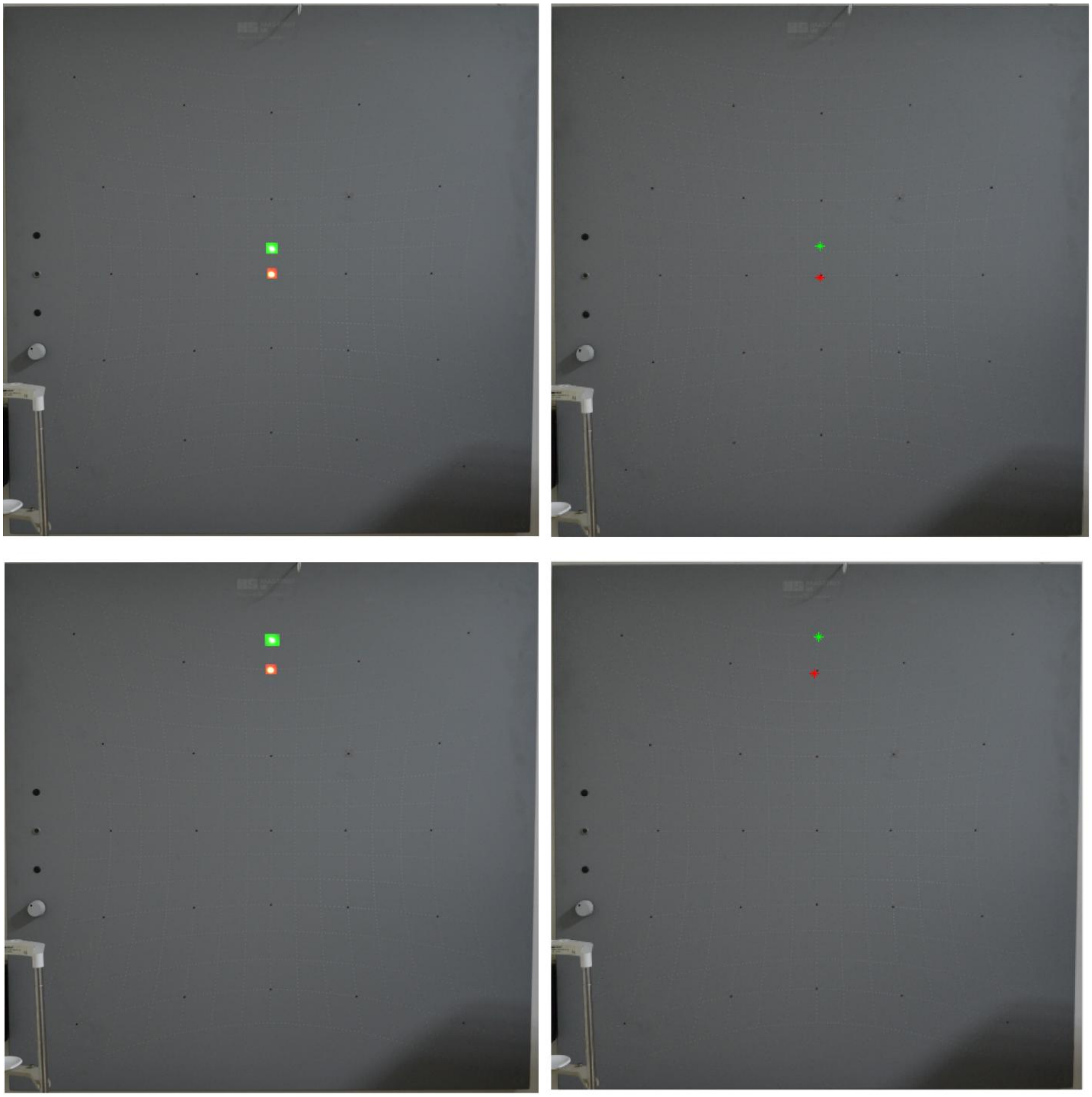
We have widely tested our automated system acquired Hess screen images. We have tested whole algorithm of this automated system for the acquired data base using two parameters i.e. visual inspection and accuracy.

4.2.1 Visual Inspection

Human visual inspection is the best and fastest way to validate the results generated by any automated algorithm. But it is very simple and biased method of inspection and it doesn't give results with very well details.

4.2.1.1 Red-Green Points extraction

This step is used to extract the red-green point's location from the acquired image. This step is very important and should be done very carefully because finding the exact location of points is very important and whole automated diagnosis systems depend on this. An expert can easily verify between the well extracted points and wrongly extracted points. Visual inspection results of point extraction algorithm technique are shown in figure 4.2.



(a) (b)

Figure 4.2 Red-Green Point Extraction Results a) Acquired Image b) Point Extracted Image.

By using visually inspection we can see that point's location is extracted with high accuracy.

4.2.1.2 Hess Chart Plotting

In this step we plot the Hess chart by joining the extracted point in a special manner described by the medical theory of Hess Screen. This part is important for visually diagnosing the disease. Following figure 4.3 shows the plotting of Hess plot with nicety.

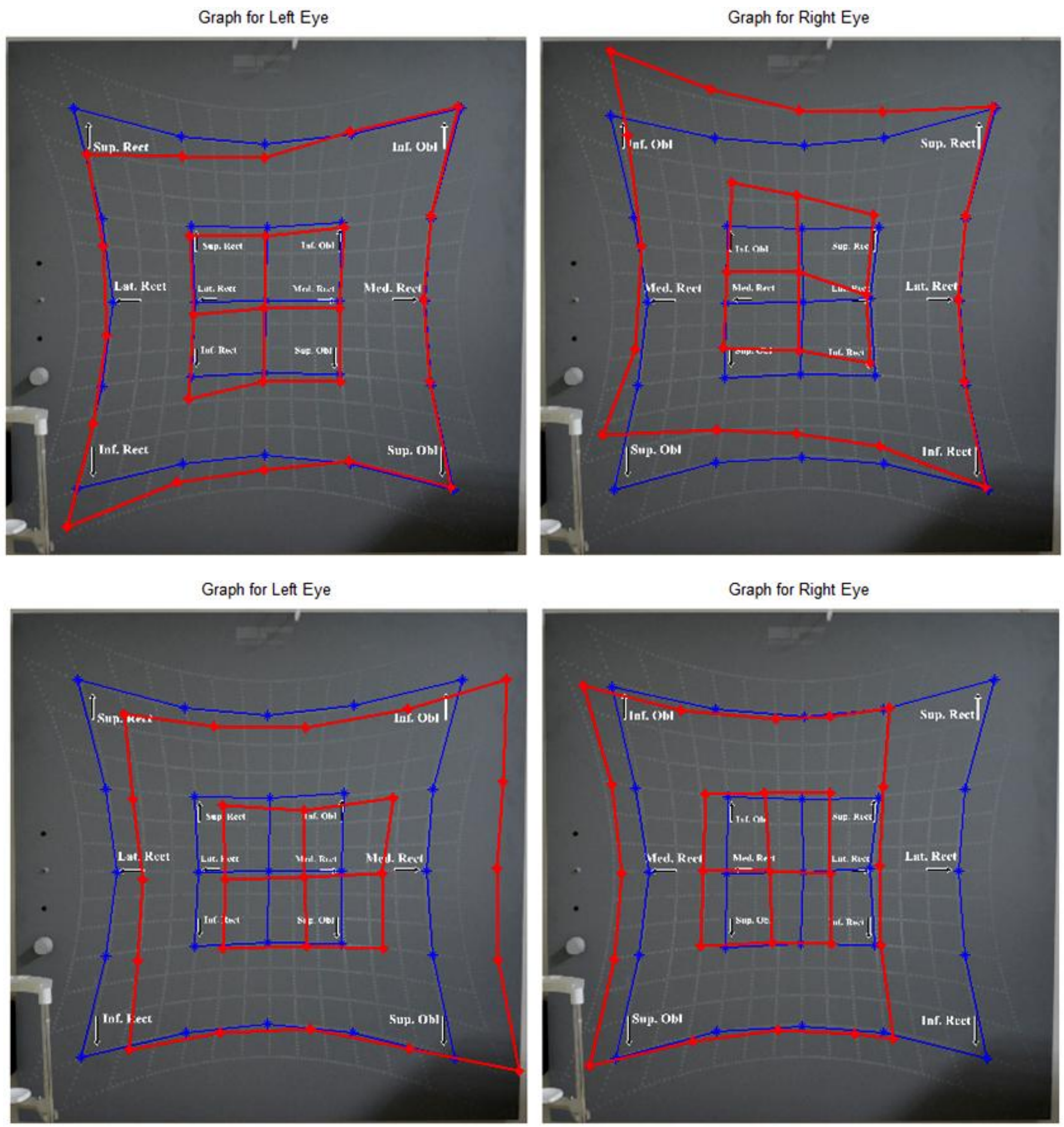
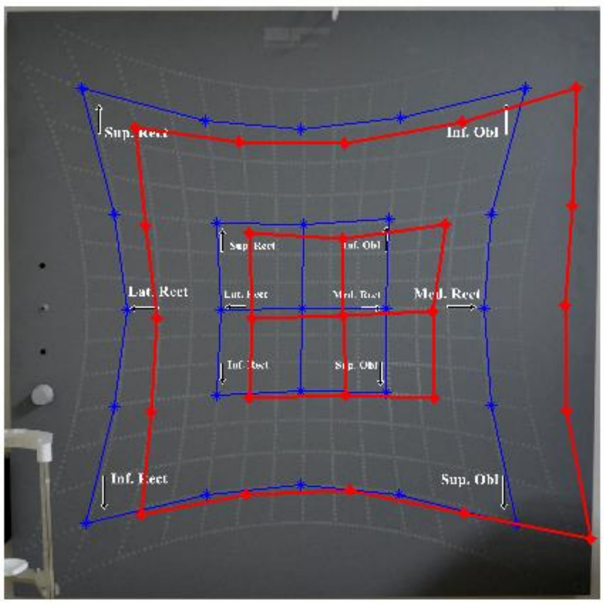


Figure 4.3 Hess Chart Plotting Visual Inspection

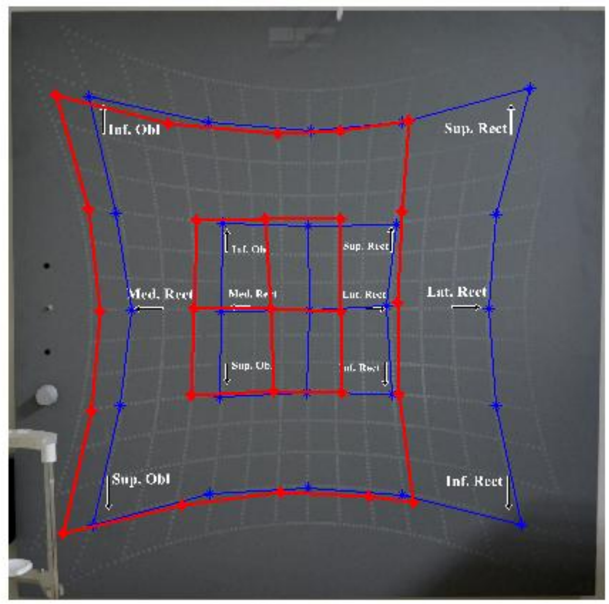
4.2.1.3 Automated Diagnosis System (CAD)

Automated diagnosis system consist of three analysis, inner square analysis, fixation point analysis and outer square analysis. This system gives us result in two parts. First parts describe the details finding of Hess plot. Findings includes, muscles states of both eyes, fixation point deviation and direction and disesed eye. Second part tells us about the provisional Diagnosis. Visualy we can accurately confirm the findings which we have implemented using our automated system. Visual inspection of autoamted diagnosis system gives about 100% reliable results in findings as it just deals with the telling about the states of muscles and centre point deviation. But for the visaual diagnosis, it could be difficult to get this much accuracy.

Graph for Left Eye



Graph for Right Eye



|||******************************~~Findings~~******************************|||

In the Right Eye: - -Center point is deviated by 0.071! Degree Superiorly and 6.785! Degree Nasally!

-Insignificant Right Esotropia Detected! which remain same on elevation but decreases on depression!

In the Left Eye: - -Center point is deviated by 1.071! Degree Inferiorly and 7.00! Degree Nasally!

-Insignificant Left Esotropia Detected! which remain same on both elevation and depression!

-Right Eye has smaller inner field vision and Left eye has larger inner field vision!

In the Right Eye Muscles states are: **-** Lat.Rect is underacting, Med.Rect is overacting,

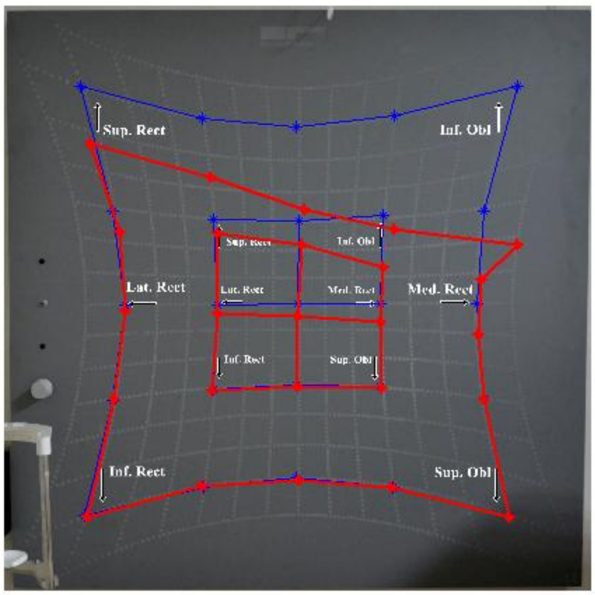
In the Left Eye Muscles states are: - Lat.Rect is underacting, Med.Rect is overacting,

|||****************************~~Diagnosis~~******************************|||**

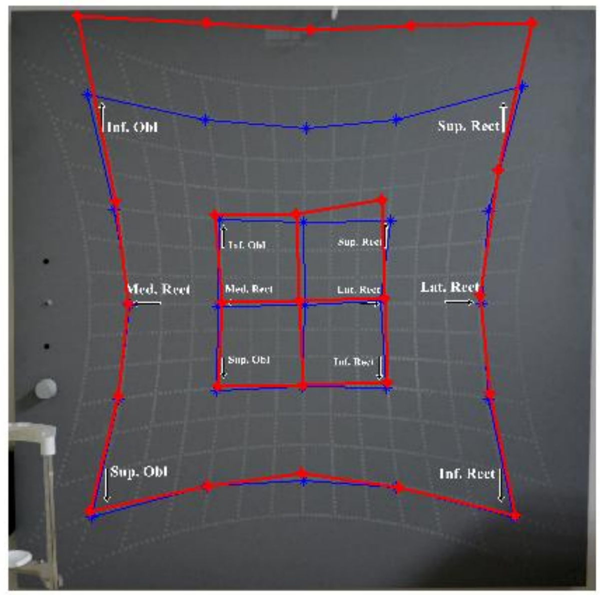
-Lateral Rectus (VI Nerve) Palsy, "Right Eye"!

Above and following are some results of automated system findings and diagnosis. These results show the 100% accurate in findings and 95% accuracy in finding diagnosis according to visual inspection by ophthalmologist.

Graph for Left Eye



Graph for Right Eye



|||****************************~~Findings~~******************************|||**

In the Right Eye: - -Center point is deviated by 0.642! Degree Superiorly and 1.000! Degree Nasally!

-Fixation Point is Normal

In the Left Eye: - -Center point is deviated by 2.142! Degree Inferiorly and 0.071! Degree Temporally!

-Fixation Point is Normal

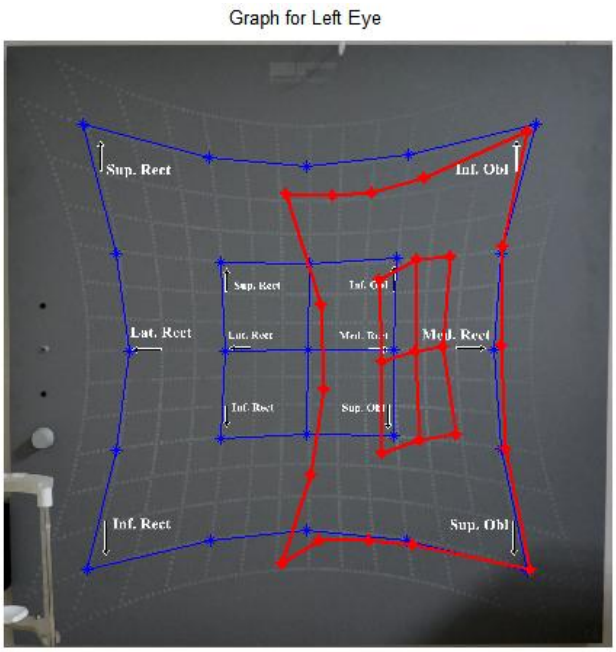
-Left Eye has smaller inner field vision and Right eye has larger inner field vision!

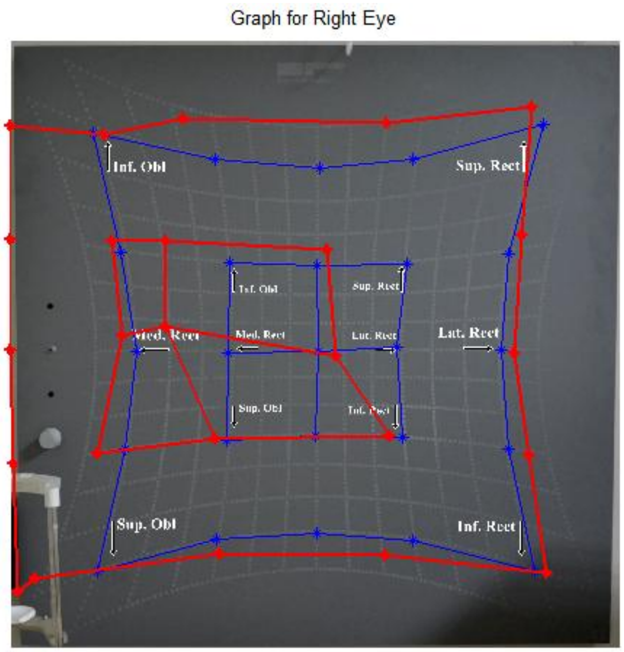
In the Right Eye Muscles states are: **-** Inf.Obl and Sup.Rect are overacting.

In the Left Eye Muscles states are: - Inf.Obl and Sup.Rect are underacting.

|||****************************~~Diagnosis~~******************************|||**

-Restriction in the left orbital floor. Clinical Co-relation Advised!





|||******************************~~**Findings**~~******************************|||

In the Right Eye: - -Center point is deviated by 4.142857! Degree Superiorly and 25.857143! Degree Nasally!

-Right Esotropia Detected! which remain same on elevation but decreases on depression!

In the Left Eye: - -Center point is deviated by 0.071429! Degree Inferiorly and 18.000000! Degree Nasally!

-Left Esotropia Detected! which remain same on elevation but increases on depression!

-**Left Eye** has smaller inner field vision and Right eye has larger inner field vision!

In the Right Eye Muscles states are: - Lat.Rect is underacting, Med.Rect is overacting.

In the Left Eye Muscles states are: - Sup.Rect, Lat.Rect are underacting, Med.Rect is overacting.

|||******************************~~**Diagnosis**~~******************************|||

-Left Duane Type I! Clinical Co-relation Advised!

This case diagnosis is not accurate. Because according to these findings it could also be the LR palsy of left eye.

4.2.2 Accuracy

In this part, method used for automation of Hess screen was evaluated by using the accuracy of results per case. In this technique we will compare our implemented results with the results given by specialist ophthalmologist. We have calculated the accuracy of each step separately.

4.2.2.1 Red-Green Point Extraction

Table 4.1 shows the accuracy attained by our proposed technique in point extraction.

Database	Accuracy
AFIO	99.8%

Table 4.1 Red-Green point extraction Accuracy

4.2.2.2 Hess Chart Plotting

Table 4.2 shows the accuracy of plotting the Hess chart in this automated system.

Database	Accuracy
AFIO	100%

Table 4.2 Hess Chart Plotting Accuracy

4.2.2.3 Automated Diagnosis System (CAD)

This is the most important part of this automated system and accuracy evaluation should be performed in carefully. After implementation, we tested our system on the dataset acquired by the AFIO and in the end we showed our results to the classified ophthalmologist of AFIO. Ophthalmologist marks the accuracy of findings and provisional diagnosis separately. In the end we calculate the average accuracy of the diagnostic system. This automated system diagnoses the disease based upon the inner square analysis, fixation spot analysis and outer square analysis. Following table shows the accuracy of finding’s and diagnosis separately and in the end overall accuracy and average accuracy of total system has also been calculated.

Case no	Finding Accuracy	Diagnosis Accuracy	Overall Accuracy
1	1	0.95	0.975
2	1	0.95	0.975
3	1	1	1
4	1	0.80	0.9
5	1	0.90	0.95
6	1	0.80	0.9
7	1	0.95	0.975
8	1	0.80	0.9
9	1	0.90	0.95
10	1	0.95	0.975
11	1	0.80	0.9
12	1	0.90	0.95
13	1	0.95	0.975
14	1	0.85	0.925
15	1	0.75	0.875
16	1	0.90	0.95
17	1	0.80	0.9
18	1	0.95	0.975
19	1	0.95	0.975
20	1	0.90	0.95
21	1	0.80	0.9
22	1	0.85	0.925
23	1	0.85	0.925
24	1	0.75	0.875
25	1	0.80	0.9
Average	100%	87%	93.6%

Table 4.3 Automated Diagnosis System Accuracy.

Following graph show the accuracy plot of the automated diagnosis system.

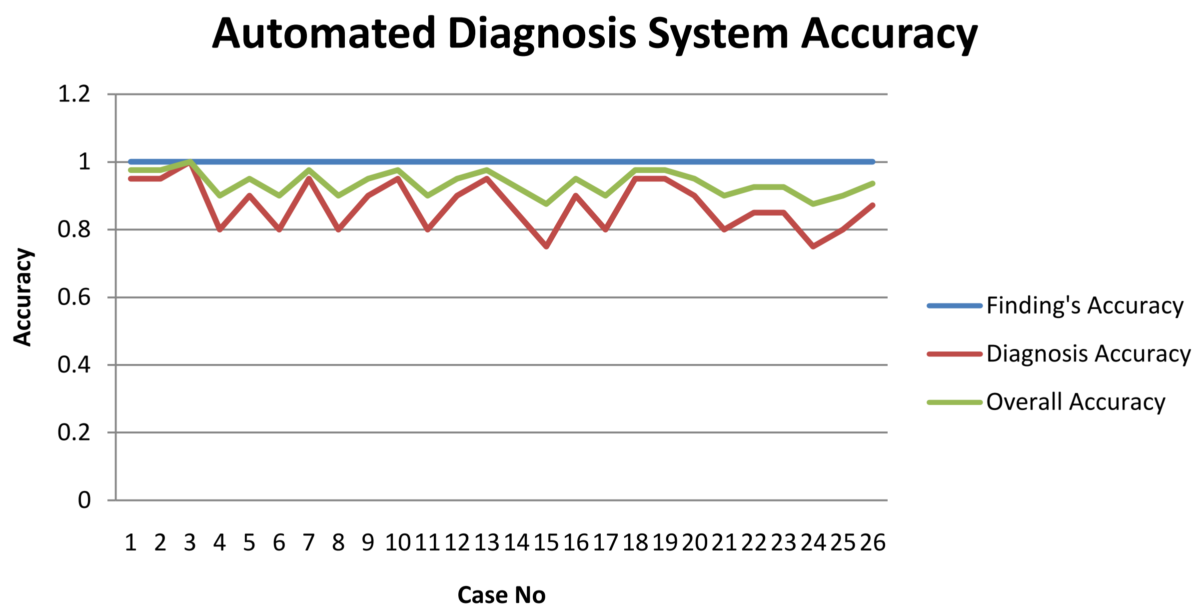


Figure 4.4 Accuracy Plot of Automated Diagnosis System

We can observe that, this system of automated diagnosis has achieved an overall accuracy of 93.6%.

4.3 Summary

All of the proposed methods have been tested on the acquired data set. We have evaluated our results on the basis of two inspections i.e. visual inspection and accuracy. The point extraction part of algorithm has achieved an accuracy of 100% and Hess chart plotting part has also achieved the same accuracy of 100%. The most important part of this automated diagnosis system which was consisting of three parts has also achieved high accuracy of 100% in findings and 87% accuracy in diagnosing the disease. Overall accuracy for this automated diagnosing system has been more than 93%. The proposed system has been evaluated very carefully and results show that proposed system performance is very efficient.

Chapter 5: Conclusion and Future Work

5.1 Conclusion

The traditional Hess screen is an imperative instrument which is primarily employed for the measurement of paralytic strabismus. This instrument is useful for checkup of extraocular muscles of eyes. It provides quantitative analysis about muscles states and category of strabismus. In hospital, the results are used to diagnose the disease as paralytic strabismus or restriction in orbit, so that the patient can be treated accordingly. The conventional Hess screen is difficult to operate, more time consuming and manual in use

The purpose of this thesis is to develop automated system of Hess Screen instrument for diagnosing paralytic strabismus. First step of the automated system is image acquisition. We have used a USB digital camera which will take the images of the Hess Screen during the test. The acquired image contains the red and green points of each mark. In the second stage of point extraction, we will first split the acquired image into red and green channel images. Then we will pass these images through the preprocessing step. In this step a median filter will be applied on the red-green channel images to remove the noise and smoothing the image without losing any information. After preprocessing, we will apply moving average window to calculate the maximum intensity region in the red and green channel images. Region which contains the maximum value in green channel will be the location of the green point in the image and the region containing maximum intensity value in the red channel image will be the location of red point. After extracting the point we will store all these points for further processing. In next step we will plot the Hess plot according to the medical principal of Hess Chart. This plotting will give us visual idea about the pathology of the eye. This plot will give us one inner square consisting of 9 inner points and outer square consisting of outermost 16 points. In the last step we have designed a computer aided diagnosis algorithm for automated diagnosis of disease. This is the most important step of our thesis. This algorithm is consisting of three type of analysis. First one is Inner square analysis. In this his analysis, we have to calculate the inner square area of each plot. Plot with the smaller area will be considered as the diseased eye. So this analysis is very important. Second is fixation point analysis. This analysis tells us about the type and state of tropia present in the eyes. We have used fuzzy logic technique to develop this part of automated system. The third analysis is the outer square analysis. This analysis also incorporates the fuzzy logic technique. In this analysis, we have to find the muscles state and then according to medical theory of Hess Screen we have to check combination of different muscles according to rules defined by Hess chart theory. In the end we had diagnosed the disease by combining the effect of all three analyses.

The developed technique has been test on a dataset which was acquired with the help of AFIO. Images of the Hess screen was acquired during the test and used by the proposed technique for the evaluation. Two parameters were used to for evaluation i.e. visual inspection and accuracy. The proposed method of point extraction and Hess chart plotting has achieved an accuracy of 100%. The algorithm of CAD which was consists of two parts of findings and diagnosis has achieved an accuracy of 100% for findings and 87% accuracy for diagnosis. This final diagnosis system has achieved an overall accuracy of more than 93%. The evaluation of this automated system is done by installing it in a well known local ophthalmology hospital and the results confirmed that this automated, more accurate and easy to use system can be replaced by traditional Hess screen instrument in hospital.

5.2 Future Work

This automated system of Hess screen for diagnosis of paralytic strabismus is half part of complete automated system. In Complete system includes conversion of code from MATLAB to OpenCV and installation of prototype of complete system in AFIO which will replace the traditional instrument.

References

[1] Strabismus (Crossed Eyes). American Optometric Association www.aoa.org/x4700.xml#1

[2] Roper-Hall G. The Hess screen test. Am Orthopt J. 2006; 56:166-74. doi: 10.3368/aoj.56.1.166.

[3] Zhao JianShan. The Clinical Application of HESS Screen, Chinese Journal of Practical Ophthalmology, Vol.10, No.2,1992: 105-106.

[4] J Michel Millodot. Dictionary of Optometry and Visual Science, 7th edition

[5] Sinoj Thomas. Eye Muscles, muscles of the eye, the eye muscles. http://medical-transcriptionist-reference.blogspot.com/2012/05/eye-muscles.html

[6] Jack J Kanski, Brad Bowling. Clinical Ophthalmology. 7th ed.

[7] The Extraocular Muscles. Ted M. Montgomery, Optometric Physician. http://www.tedmontgomery.com/the_eye/

[8] Strabismus (Crossed Eyes). American Optometric Association. http://www.aoa.org/x4700.xml#1

[9] CROSSED EYES (Strabismus). Dictionary of Eye Terminology. http://www.triadpublishing.com/eyecarereports/strabismus-book.shtml

[10] Roper-Hall G. The hess screen test. Am Orthopt J. 2006; 56:166-74. doi:10.3368/aoj.56.1.166.

[11] Zhao Jian Shan. The Clinical Application of HESS Screen, Chinese Journal of Practical Ophthalmology, Vol.10, No.2,1992: 105-106

[12] Michel Millodot. Dictionary of Optometry and Visual Science, 7th edition.

[13] Hess Charting. Dr. Jitendra Jethani. *MS, DO, DNB, FNB.* http://www.ejournalofophthalmology.com/ejo/ejo55.html

[14] R. Boyle and R. Thomas *Computer Vision: A First Course*, Blackwell Scientific Publications, 1988, pp 32 - 34..

[15] J. Mendel. Fuzzy logic systems for engineering: a tutorial. Proceedings of the IEEE, 83(3):345{377, Mar 1995.

[16] Wei BingZhang, Han XiaoPeng and Zhao FuQiang. Automation of HESS Screen test for ophthalmology by using correction algorithm of geometry distortion of space image, Information of Medical Equipment, No.3, 1996:7-10

[17] Ma ZongLian. Automation of Hess Screen test for ophthalmology, Chinese Journal of Medical Instrumentation, Vol. 20, No.5,1996: 181-282

[18] Cao GuiLian. The Application of HESS Screen in eye-muscle Test, JiLin Journal of Medical Information, No.4,1994:22.

[19] Liping Wang, Dong Yu. A digital diagnosis instrument of Hess screen for paralytic strabismus. 6-8 July 2007. ISBN: 1-4244-1120-3. Pages: 1234 - 1237

Appendix: Abbreviations

CN	Cranial Nerve
CAD	Computer Aided Diagnosis
LED	Light Emitting Diode
FL	Fuzzy Logic
MR	Medial Rectus
LR	Lateral Rectus
SR	Superior Rectus
IR	Inferior Rectus
SO	Superior Oblique
IO	Inferior Oblique
CNS	Central Nervous System
GUI	Graphical User Interface
RGB	Red, Green and Blue

Automated System of Hess Screen for diagnosis of Paralytic Strabismus using Computer Aided Diagnosis

Abubakar Yamin†, Shoab A. Khan‡ and Ubaid-Ullah Yasin§
Department of Computer Engineering
College of Electrical & Mechanical Engineering
National University of Sciences and Technology, Islamabad, Pakistan.
abubakar.yamin@gmail.com†, shoabak@ceme.nust.edu.pk‡, talhaubaid@gmail.com§

Abstract— **In Ophthalmology, Hess screen is an imperative instrument which is primarily employed for the measurement of paralytic strabismus. Strabismus is the state of eye in which eyes are not properly aligned with each other and patient complaint for double vision (diplopia). In this paper we propose a model for the automation of traditional Hess Screen instrument for the diagnosis of strabismus, at present which is totally manual consume lot of time of patient as well as ophthalmologist. We present a three stage system consisting of image acquisition, point extraction, plotting and computer aided diagnosis algorithm. First stage is composed of a digital camera which will take images of the HESS board and transfer it to a computer. In second stage image processing techniques are used to extract points from images to draw HESS plot, and in third stage an algorithm based on fuzzy logic is designed which will automatically diagnose the paralytic strabismus using statistics of the Hess graphs. This system is convenient, fast and has an ability to manage medical record with refinement. The evaluation of proposed system is performed by using dataset provided by well known local hospital.** (***Abstract***)

Keywords—Hess screen; opthalmology; paralytic strabismus; diplopia; image manipulation; fuzzy logic;

I. INTRODUCTION

The traditional Hess screen is an imperative instrument which is primarily employed for the measurement of paralytic strabismus. This instrument is useful for checkup of extraocular muscles of eyes. It provides quantitative analysis about muscles states and category of strabismus. In hospital, the results are used to diagnose the disease as paralytic strabismus or restriction in orbit, so that the patient can be treated accordingly. The conventional Hess screen is difficult to operate, more time consuming and manual in use. Automation of traditional Hess screen will able the ophthalmologist to perform the test in less time and diagnose the disease with nicety, quickly and more accurately.

Little research has been undertaken in the field of Hess chart test. In 1996, Wei Bingzhang urbanized a new technique which takes images of the light mark released by patient using a TV camera and then exercised correction algorithm based on geometric distortion of space image and as a final point printed the outcome of HESS chart test. All of the system management including acquiring images was executed by an unusual signal lamp which was connected with computer using wireless [1]. In 1998, Ma Zonglian build up an improved technique which utilized green facular electric torch attached with planar increment angle encoder. It drives angle indication to a sole chip to produce the outcome of Hess chart test [2]. Cao GuiLian presented a system of diagnose and analysis which compare patient's Hess chart with the already diagnosed Hess chart stored in the database to differentiate the muscular torticollis and ocular torticollis[3].

In 2007 Liping Wang proposed a new digital instrument for strabismus diagnosis. He replaces the traditional Hess Screen Instrument with a 20" LCD screen and implemented a java based testing software. His system was capable of holding medical record or patients [4].These techniques are still intricate to handle, and its take lot of time and expert assistance to perform the test. These techniques advances way of result recording, but have no automated system for diagnosis and analysis of result. So, ophthalmologists anticipate having a new automated system which must be simple to drive, less in cost, performance with nicety, and can support the automated diagnosis system.

In this paper we proposed a new automated system of Hess screen test for strabismus diagnosis. This technique incorporate image manipulation and software based diagnosis algorithm which detects the type of strabismus as paralytic or restriction. Our proposed technique is based on the method of creating traditional Hess chart, medical theory of Hess chart and characteristics of extraocular muscles of eyes.

This system is composed of computer aided diagnosis (CAD) algorithm, digital camera, computer with printer, traditional Hess screen, green laser torch and red/green goggles. We automate the traditional Hess charting method along with the self diagnosis system instead of replacing or making any change in it. It increases the rank of the intelligent diagnosis and scrutinizes records wisely, and requires less effort by specialist to perform the test. The automated system of Hess screen for strabismus diagnosis is comprises of automated Hess screen check up, patient's medical record management system and automated result diagnostic system. It offers amalgamation function of automated diagnosis of strabismus, data documentation and scrutinize.

II. MEDICAL THEORY OF HESS SCREEN

The Hess screen test was intended by a renowned neurophysiologist Walter Rudolf Hess in 1908. HESS was honored with the Nobel Prize in 1949 for his research in the field of functional organization of the vegetative nervous system [5]. The basic principal of HESS screen test is foveal projection [6]. This test uses red/green goggles to break the binocular fusion of both eyes. This exploits the ocular deviation. Patient hold's a green foster torch which he used to project on fix marks on the board.

HESS screen is a black tangent electronically operated screen with small red LED's which is used for evaluating and grading strabismus [7]. It consists of a chart separated by white lines into small segments of 5º divisions [7]. Where straight vertical and horizontal line crosses each other that point is called center point or fixation point. There are small red LED's at the particular spots on the lines in the eight major meridians demonstrating locations 15º and 30º from the fixation point. Patient wears red/green goggles to brake the fusion of red and green light. Eye covered with red glass is known as fixed eye and other eye which is covered by green glasses is testing eye.

The traditional Hess screen test procedure is mentioned as under: Patient is asked to sit at a distance of 0.5 m from the centre of the screen and wears red/green goggles. Right eye is tested first followed by the left eye. So, green glasses will be on right eye and red glasses on the left eye. There are twenty five glowing LED's marks on the board. Ophthalmologist or Orthoptist glows the LED's one by one and asks the patient to superimpose the green torch point on the glowing red spot. If the patient eye is not diseased or restricted then he/she can point it successfully. If the patient is having restricted pathology or suffering from paralytic strabismus then he/she cannot place the green marker on the red glowing spot. After that the doctor notes down green mark's position on Hess chart and then glow the next LED for the patient to carry out same procedure again. After that the doctor changes the red/green glasses position. Now green glass will be placed in front of left eye (testing eye) and red glass will be placed in front of right eye (fix eye) and doctor will repeat the same procedure again. In traditional Hess screen test doctor requires to turn on twenty five red marks for each eye and note down the location of each mark on the plot in darkroom. It makes this test vague and required lot of time by a specialist to perform this test.

III. AUTOMATED HESS SCREEN DESIGN

In this article, according to medical theory of Hess screen test we present a new technique for the automation of traditional Hess screen diagnosis instrument. With this automation technique Hess screen test will become more convenient, will take less time to perform and results will be more precise. The proposed system consists of traditional Hess screen instrument, image acquisition using camera, red/green point extraction from images, Hess chart plotting and analysis of results using CAD system. Figure 1 show the flow diagram of proposed technique.

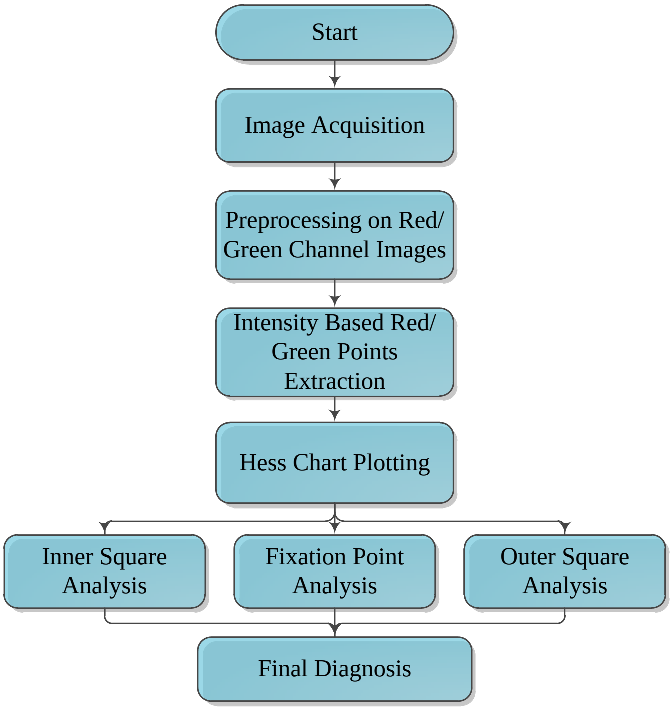


Fig. 1. Flow Diagram of Proposed Technique.

A. Image Acquisition

First stage of proposed system is image acquisition. We used the traditional Hess screen instrument without making any change in it. This instrument consists of traditional Hess screen, red/green goggles, green torch and digital webcam. Hess screen containing red LED's is connected to computer. Webcam is mounted on the top of patient chin stand and connected with computer using universal serial bus (USB) port. Testing procedure is same like traditional Hess charting but doctor have to press enter key to take color image of the board using webcam instead of noting green marks on a Hess chart. This image contains current position of red and green marks. After taking image computer automatically turn on the next LED and patient has to position green marker for next red LED. The RGB image containing red and green marks of current position is then sent to the computer.

B. Point Extraction and Graph Plotting

In the second stage, red and green point extraction from image and plotting of Hess plot on the basis of extracted points is performed. Red/green points are extracted from the RGB image using a new and very simple technique. A color image is consist of three frames of Red, Green and Blue. For extracting red and green point from the grabbed color image first we take the red frame and green frame separately as an image. After separating the frames pre-processing is applied on each frame. In pre-processing median filter is applied. Median filter is used because it removes noise and smoothen the image while preserving edges and useful information in the image. Such pre-processing step is used to improve the results of later processing.

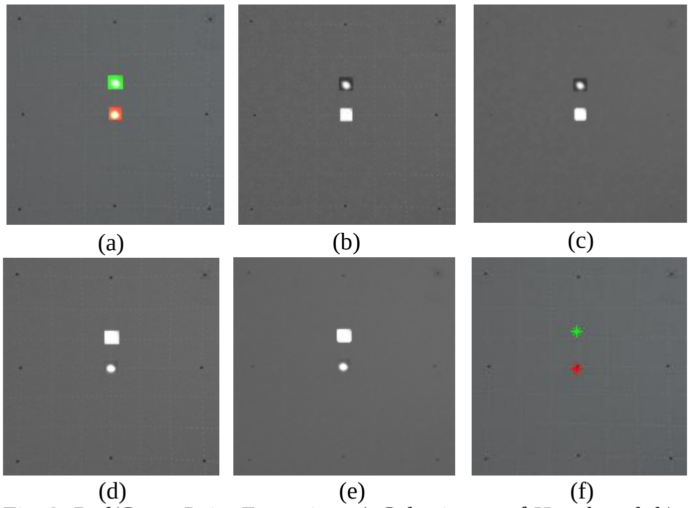


Fig. 2. Red/Green Point Extraction. a) Color image of Hess board; b) Red channel image; c) Filtered Red channel image; d) Green channel image; e) Filtered Green channel image; f) red/green marks detected

Preprocessed images of red and green channel give distinctive information about red and green marks. In the red channel image it gives highest intensity value only at the pixels of red mark and in green channel it gives highest intensity value only at pixels of green mark. In our proposed method, to detect the red or green marks we used a moving average window of 5x5. We will move this window from first to the last pixel of each image. At each location, it will calculate the average of 24 neighboring pixels including current pixel. Our proposed system will select the pixel as target where the average intensity value will be the highest. So, when we used this method on preprocessed red channel image it easily detected the red mark which has the maximum intensity value in the image and for the green channel image it detected the green marks with refinement. Instead of relying on single pixel value we include neighboring pixels which will give more accurate assumption of red or green marks in image. Figure 2 shows the grabbed Hess board image during test with red and green marks, red/green channel images, filtered red/green channel images and image with the detected point.

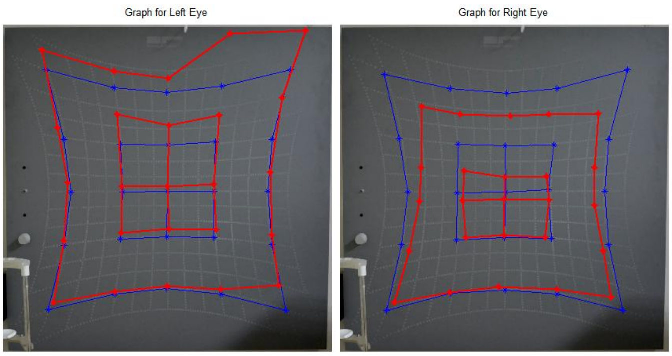


Fig. 3. Hess Chart Plotting of a diseased Eyes.

After extracting all points from the images we have obtained 25 points for each eye. We have to join the points according to Hess chart theory to make an inner and outer square. Figure 3 shows a plotted Hess chart for both eyes. Blue lines shows the fix plot created by joining the fix red marks and red lines shows the plot created by joining the green points.

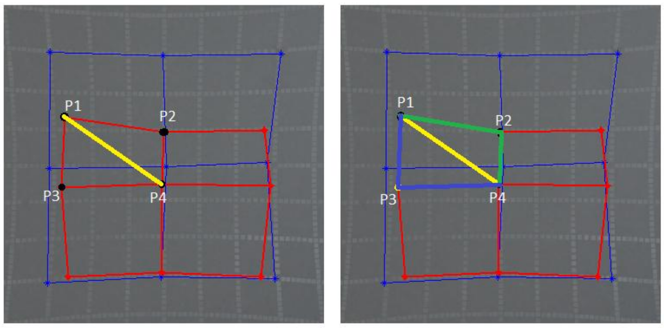
C. *Automatic Diagnosis System*

The last stage of proposed system is the automatic diagnosis system for strabismus. According to the medical theory of Hess Charting the diagnosis of Hess chart is based on the inner square analysis, fixation spot analysis and outer square analysis. In the end this system will automatically diagnose the type of strabismus based on these analyses.

I. *Inner Square Analysis*

In medical theory of Hess chart inner square analysis is very important. Eye with smaller inner square area is considered as diseased eye. So it is very important to calculate the inner square area very accurately. From figure 3 we can see that inner square is not in some proper shape like square, triangle, cube sphere or rectangle. So, we cannot apply any straight shape area finding formula on it. In our proposed method we implemented an easy and much accurate technique to find the inner square area. .

In figure 3 we can see that inner square is sub divided into four small squares. But they are also not in some proper shape. In our proposed technique we further divide each small square of Inner Square into two parts as shown in figure 4(a).



(a) (b)

Fig. 4. Inner Square Area finding a) Dividing small box into two parts; b) making two triangles from small box.

Each small square is composed of four points. We have found the distance from point P1 to P4 by using distance formula which is defined as

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (1)$$

Finding the distance'd' will divide our inner smaller square into two triangles. Point P1, P2 and P4 make first triangle and point P1, P3 and P4 make second triangle. Figure 4(b) shows the making of two triangles of small square. We will find the lengths of remaining sides of triangle by using the same distance formula. After calculating the lengths of sides now we will apply heron's formula on each triangle to find the area. Calculation of area using heron's formula is defined as

$$Area_{triangle} = \sqrt{s(s-a)(s-b)(s-c)} \qquad (2)$$

Where's' is the semi-perimeter of triangle and defined as

$$s = \frac{a+b+c}{2}$$

Where a, b and c are the sides of triangle. After calculating area of both triangles we will add both areas and this is how we will get the area of one small square of Inner Square. Similarly we have to find the area of remaining three small squares of Inner Square. In the end we will sum up the areas of all small squares to get the total area of Inner Square. Same procedure will be done to find the inner square area of other eye. Now we can easily detect the diseased eye by comparing the inner square areas of both eyes calculated using this accurate technique.

II. Fixation Point Analysis

Fixation Point is the center point of the Hess Plot. This is also called the ‘primary position of eye’. This position is considered as reference point which is at zero degree. In this position none of the muscles is contracted or relaxed. Deviation of this point from origin tells us about the state of tropia. Zero to five degrees deviation has considered as normal. Five to eight degrees deviation has considered as insignificant and deviation greater than eight degrees has considered as significant.

We have used Fuzzy logic technique to design this diagnosis system. In this system we have calculated the distance of fixation point from the origin in x-y axis direction. Direction of the distance is very important as it told us about the type of tropia. Upward (negative x-axis) deviation represent hypertropia, downward(positive x-axis) deviation shows hypotropia, deviation toward Nasal(along y-axis) side represent esotropia and outward deviation represent exotropia Figure 5 shows the different cases of tropia.

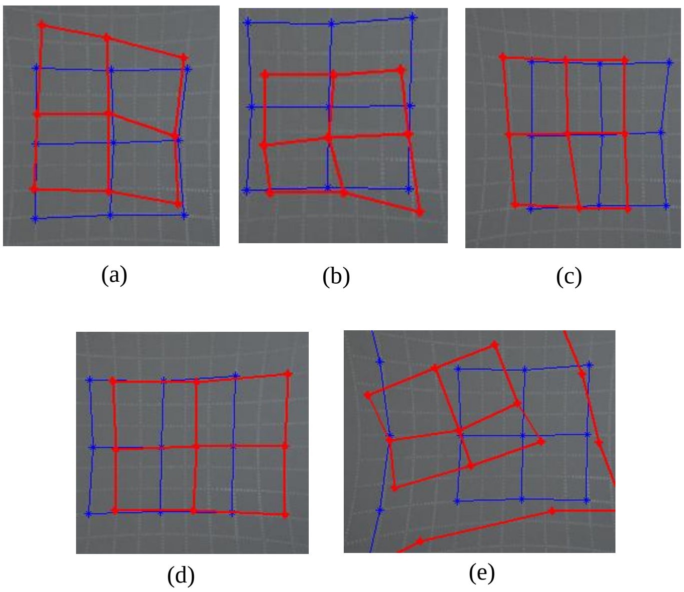


Fig. 5. Fixation Point Analysis a) Right Hypertropia b) Left Hypotropia c) Right Esotropia d) Left Esotropia e) Left Exotropia.

After observing direction of distance we gave this input to fuzzifier. According to the membership function fuzzifier describe the distance state as normal, insignificant or significant. After fuzzification, inference based on set of rule has been applied. These set of rules are based on direction and situation of distance from origin. An example of inference rule is given below

$$IF\ (eye == right)\ AND\ (type == hypertropia)...$$
$$AND\ (state == insignificant)\ THEN\ command\ is...$$
$$'Insignificant\ Right\ Hypertropia'$$

By applying these rules we will get the results. These results tell us about the type and state of tropia. Above defined rule should conclude that there is significant hypertropia is present in the right eye. We have used 14 different rules in fixation point analysis.

III. Outer Square Analysis

Each point of Outer Square is positioned at thirty degree from the origin. Outer square analysis is important for analyzing the states of muscles as normal, underacting or overacting. We will consider only six points from outer square. Each point will represent one of the extraocular muscle of eye. Four corner points of outer square represent the four vertical plane extraocular muscles (Inferior Rectus, Inferior Oblique, Superior rectus and Superior Oblique) and middle points of right and left side of square represent the horizontal plane extraocular muscles (Medial Rectus and Lateral Rectus). There are three nerves associated with these muscles for nerve supply. Lateral Rectus get its nerve supply from VI Abducens nerve; Superior Oblique get its nerve supply from IV Trochlear nerve and all other muscles Superior rectus, Inferior rectus, Medial rectus and Inferior oblique get their nerve supply from III oculomotor nerve [8].

In our system outer square analysis system is also based on Fuzzy Logic. In the diseased eye which we have detected using the smaller inner square area, We have to calculate the distance of each muscle point from their reference point and give that distance as input to the fuzzifier. Fuzzifier converts this input into fuzzy value as normal, underacting or overacting. 5^0 displacement from the reference point has to be considered as normal, displacement greater then $+5^0$ degree has to be considered as overacting and displacement shorter than -5^0 degree has to be considered as underacting.

Same six points of Inner Square also represent the same muscles states so we will also consider the displacement of the inner square points in our calculations. After fuzzification we will apply rule based inference on the fuzzy inputs. Rules are designed according to the medical theory of Hess Chart in which we have to analyze the states of different muscles and have to diagnose the palsy accordingly. Following is an example of outer square analysis inference rule

$$IF\ (right\_superior\_oblique == underacting)...$$
$$AND\ (right\_inferior\_oblique == overacting)...$$
$$AND\ (left\_inferior\_rectus == overacting)...$$
$$AND (left\_superior\_rectus == underacting)...$$
$$THEN\ command\ is\ 'Right\ Eye\ Superior\ Oblique$$
$$(IV\ Nerve)\ Palsy'$$

This rule based system have to select the major underacting muscle in the diseased eye, then its antagonist muscle which should be overacting and in the same eye, then in the other eye it should check yoke muscle which should be overacting and antagonist of that yoke muscle should be underacting. Similarly we have implemented 14 rules for each eye which can diagnose nerve palsy, restriction in orbit and Duane cases. Figure 6 and figure 7 show the diagnosis based on outer square analysis.

IV. Results and Analysis

The evaluation of automated system of Hess Screen was the most important part of this article and has been done very cautiously. We installed this system in Armed Forces Institute of Ophthalmology Rawalpindi and take the images of board during Hess chart test. We collected total of 25 test cases images and applied this automated diagnosis system on these images. After automated diagnosis, results were sent to the ophthalmologists of same hospital for evaluation.

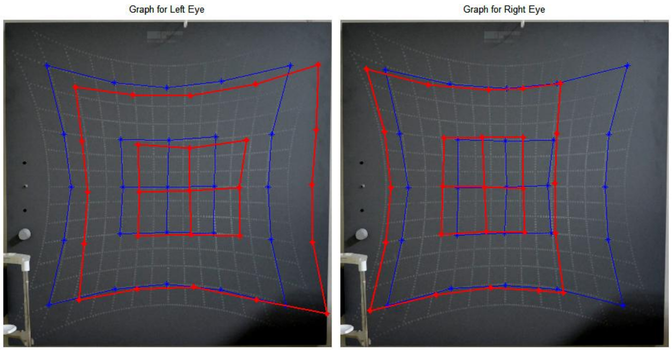


Fig. 6. Diagnosis: Right Lateral Rectus VI nerve Palsy.

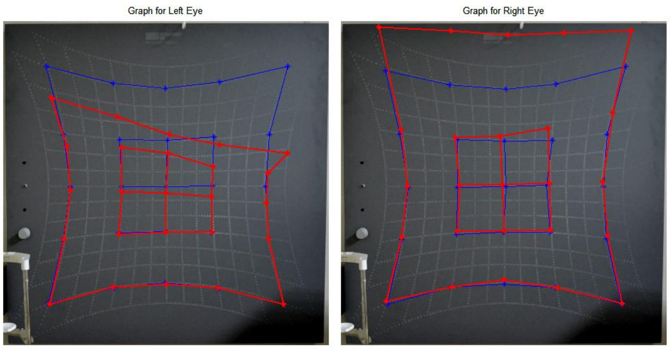


Fig. 7. Diagnosis: Restriction in Left Orbital Floor.

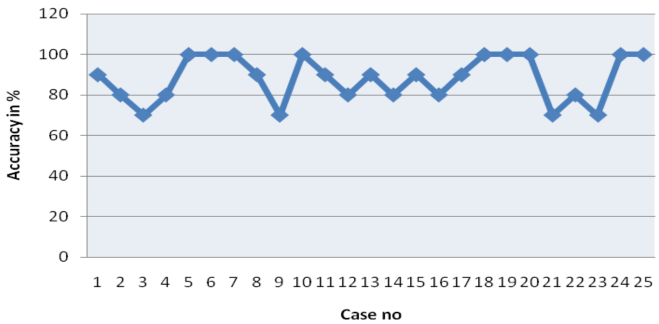


Fig. 8. Accuracy Plot of Proposed System.

They marked the accuracy of diagnosis results against each case. Figure 6 and figure 7 shows some results generated by proposed system. Figure 8 shows the accuracy plot of each case obtained by this system. According to the evaluation this automated system of Hess screen has achieved a mean accuracy of 88.4%.

V. Conclusion

The Hess Screen is an imperative diagnosis device in ophthalmology. It is employed for the diagnosis of paralytic strabismus. The usual Hess charting technique is difficult to operate, more time consuming and manual. In this paper we presented an automated system of Hess screen instrument for diagnosis of paralytic strabismus. This system automatically performs the Hess screen test and generates the results automatically. This system is composed of three stages. In first stage image acquisition is performed using a USB webcam. In the second stage red/green marks extraction from images using image processing technique and plotting of Hess chart according to medical theory of Hess Chart has been performed. In third and the final stage system has automatically diagnose the type of disease based on inner square analysis, fixation point analysis and outer square analysis. Fuzzy logic technique has been used for fixation point and outer square analysis. The evaluation of this automated system is done by installing it in a well known local ophthalmology hospital and the results confirmed that this automated, more accurate and easy to use system can be replaced by traditional Hess screen instrument in hospital.

References

[1] Wei BingZhang, Han XiaoPeng and Zhao FuQiang. Automation of HESS Screen test for ophthalmology by using correction algorithem of geometry disortion of space image, Information of Medical Equipment, No.3, 1996:7-10.

[2] Ma ZongLian. Automation of Hess Screen test for ophthalmology, Chinese Journal of Medical Instrumentation, Vol. 20, No.5,1996: 181-282.

[3] Cao GuiLian. The Application of HESS Screen in eye-muscle Test, JiLin Journal of Medical Information, No.4,1994:22.

[4] Liping Wang, Dong Yu. A digital diagnosis instrument of Hess screen for paralytic strabismus. 1-4244-1120-3

[5] Roper-Hall G. The hess screen test. Am Orthopt J. 2006; 56:166-74. doi: 10.3368/aoj.56.1.166.

[6] Zhao JianShan. The Clinical Application of HESS Screen, Chinese Journal of Practical Ophthalmology, Vol.10, No.2,1992: 105-106.

[7] Michel Millodot. Dictionary of Optometry and Visual Science, 7th edition.

[8] Jack J Kanski, Brad Bowling. Clinical Ophthalmology. 7th ed.