Detection and Classification of Cataract

using Fuzzy Inference System

A project report submitted in partial fulfillment of the requirements

for the degree of Master of Philosophy in Computer Science

By

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CERTIFICATE

This is to certify that the undersigned have assessed and evaluated the Research Project D**etection and Classification of Cataract using Fuzzy Inference System** submitted by **KALYANI SAMBHOO**. The project report has been (accepted / rejected) for the partial fulfillment of the degree of Master of Philosophy in (Computer Science).

Internal Examiner	**External Examiner**
Signature	**Signature**
Name	**Name**
Date	**Date**

DECLARATION

I hereby declare that this Project Report titled **Detection and Classification of Cataract using Fuzzy Inference System** submitted by me is based on actual work carried out by me under the guidance and supervision of **Dr Sanjay Kadam**. Any reference to work done by any other person or institution or any material obtained from other sources have been duly cited and referenced. It is further to state that this work is not submitted anywhere else for any examination.

Nowrosjee Wadia College,	**Signature of the Research student**
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DECLARATION

I hereby declare that this Project Report titled **Detection and Classification of Cataract using Fuzzy Inference System** submitted by me is based on actual work carried out by me under the guidance and supervision of Dr. Sanjay Kadam. Any reference to work done by any other person or institution or any material obtained from other sources have been duly cited and referenced. It is further to state that this work is not submitted anywhere else for any examination.

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CERTIFICATE FROM THE GUIDE

This is to certify that Mrs .**KALYANI SAMBHOO** has completed the Research Project **Detection and Classification of cataract using Fuzzy Inference System** under my guidance and supervision, and submitted the project report as laid down by Yashwantrao Chavan Maharashtra Open University, Nashik. The material that has been obtained from other sources is duly acknowledged in the dissertation. It is further certified that the work or its part has not been submitted to any other University for examination under my supervision. I consider this work worthy for the award of the degree of Master of Philosophy in Computer Science.

Nowrosjee Wadia College, Pune

Signature of Guide

Name

Date

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List of Abbreviations

FIS	Fuzzy Inference System
RGB	Red Green Blue
Eg	For example (exempli gratia)
i.e	That is / to say (id est)
p, pp	Page(s)
mf	Membership Function
dat	Data
LOCS	Lens opacity classification system
etc.	And so forth
fig	figure
GUI	Graphical user interface

CHAPTER 1

INTRODUCTION

1.1 Overview

A cataract is a clouding that develops in the crystalline lens of the eye or in its envelope, varying in degree from slight to complete opacity and obstructs the passage of light. The lens of the eye consists of water and protein which allows light to pass through it and is incident on the retina[1] .With age, some of the protein in the eye begins to clump together, preventing light from reaching the retina and thus blurring the vision[2]. Cataract is considered as a condition and not a disease[3].

The white portion of the eye is called sclera, the center-most portion is the pupil and the portion between the pupil and the sclera is called the iris. A lens is located in front of the pupil. A cataract can cover the eye lens partially or completely[1]. It can be stationary, meaning its growth is in one place and slow or stopped, or it can be progressive and grow rapidly. Age-related cataract is the most common form of cataract. Age-related cataracts are morphologically classified into nuclear, cortical, and sub-capsular.

A thorough eye examination through a Slit lamp by an ophthalmologist detects the presence and the extent of a cataract[2]. If the lens of the eye appears to be cloudy the cataract is detected .

[1] Available fromhttp://12.31.13.13/HealthTopics/senior/Oct03ssMain.htm

[2] Available from: http://www.cataract.com

[3] Available from: http://shroffeye.org

Cataract is classified based on location of the opaqueness on the lens. If the opaque is at the center of the lens the type of cataract is ‘nuclear’ , if the opaqueness is at the periphery of the lens the type of cataract is ‘cortical’ .The cataract is graded by comparing the picture observed during Slit-lamp bio-microscopy with a set of standard photographs which is termed as clinical grading. The clinical grading systems are subjective and thus, they are vulnerable to inconsistencies over time and in different observers.

In the last decade, many techniques have been developed for disease detection and classification of bio-medical images. The techniques such as Hidden Markov Models and Neural Networks were used for classification. But the major problem faced by such systems is the presence of noise in an image. Sometimes the quality of an image is poor which could mislead the prediction of a disease or condition. The methods and instruments used for capturing an image also affects the accuracy of detection. As mentioned earlier the current methods used for cataract detection are subjective. So there was a need of automated system for cataract detection and classification which will minimize human intervention by employing some empirical knowledge and provide good accuracy.

In this dissertation, an effort has been made to automate the cataract detection, classification and grading method. Algorithms have been developed which detect the presence of cataract. Currently, the detector enhances the image quality, and works on cropped images which depict only the region of interest i.e. the pupil in an eye image using MATLAB functions and then computes the pixel colour which are crisp (non-fuzzy) numbers limited within a specific range are sent as input to a Fuzzy Inference System. Rules are designed which execute using fuzzy reasoning of membership functions. The input to an if-then rule is the current value for the input variable and the output is an entire fuzzy set . This fuzzy set is later defuzzified to obtain a crisp result assigning one value to the output which is a crisp result i.e. non-cataract or cataract and is further classified into its types. With little modification, proposed model can be used as a tool for semi-automated cataract detection and classification.

1.2 Aims of this Research work

The aim of this research work was to remove subjectivity and in-consistencies over time and in different observers and remove the need of an expert for detection procedure thus freeing him to do other important tasks like Cataract surgery.

In order to achieve this, the following objectives were considered in this dissertation:

1) To pre-process cataract eye image and eliminate complex background and extract only the pupil region from normal eye image and lens region from retro-illumination images.
2) To extract features like the colour of the pixels and pixel co-ordinates in the region of interest.
3) Use fuzzy inference system to fuzzify the input variables, and evaluate rules using Fuzzy reasoning. There are five parts for the fuzzy inference process: fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules using Fuzzy reasoning and defuzzification.
4) Confirmation of results by checking the uniformity of pixel colours.
5) Classification of cataract into its predefined types – nuclear and cortical ,
   if the cataract appears at the center of an image and within some allowable radius, the type of the cataract detected is nuclear, if it lies outside the specified radius the type of cataract is cortical.
6) Grading of cortical cataract on the LOCS-III scale of C1 to C5.

1.3 Problem statement

To develop an effective cataract diagnostic system and classifier with high accuracy which will solve problems associated with subjective clinical grading and removing inconsistencies over time in different observers.

1.4 Organization of Thesis

This dissertation is organized into 6 remainder of the thesis is organized as follows:

Chapter 1 – **Introduction** gives an overview of the topic and project work and states the aim and objectives of the research work.

Chapter 2 – Literature Survey provides general background of cataract and its types. It explains the existing methods used for detection. It also gives reference and an overview of similar applications.

Chapter 3 – Research Design gives information about the Research Methodology used for cataract detection, it begins with the techniques followed for extracting the region of interest from the cataract infected eye image called Image cropping. The system is developed in MATLAB environment. The detection procedure includes extraction of pixel colours and pixel co-ordinates passing them to Fuzzy inference system and extracting results from the system after defuzzification.

Chapter 4 – Data Collection gives details of data collection, preprocessing and analysis.

Chapter 5 – Results and Conclusions presents results and discussion of proposed Detector, validation methods used and computation of percentage accuracy.
Conclusions gives the aims and motivation which resulted in this research work. It briefly reviews the research work and also explains how the research work will

contribute to the welfare of the society. A comparison with related work is also mentioned. This chapter also states the limitations and scope for future work.

CHAPTER 2

Background Theory and Literature Survey

2.1 Cataract Background

A cataract is a clouding that develops in the crystalline lens of the eye or in its envelope, varying in degree from slight to complete opacity and obstructing the passage of light.

Cataract is considered as an eye disorder, which normally turns the vision blurred. Generally, older people are engulfed by this eye problem. If detected timely, it could easily be removed by surgery, but delay in its detection may also turn its removal quite difficult .

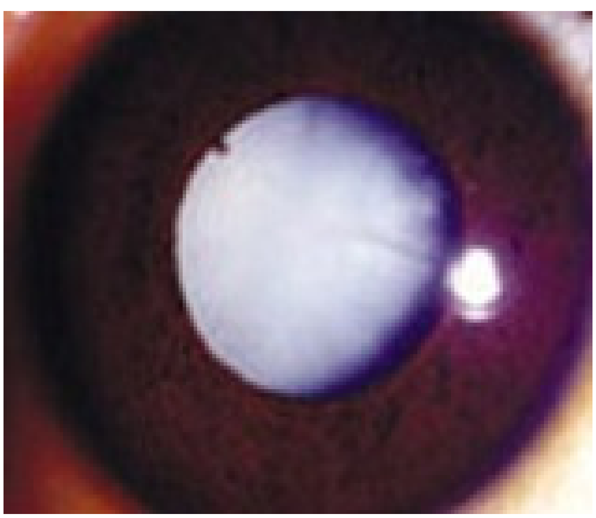


Figure 2.1 : Image of an eye with cataract

There are three regions in the image. The outer white portion is called the sclera, the central portion is black in the normal eye. In a cataract eye it appears to be white or blue, the region between the pupil and sclera is called the Iris.

A thorough eye examination by an ophthalmologist can detect the presence and extent of a cataract[1], as well as any other conditions that may be causing blurred vision or other eye problems.

2.1.1 Types of Cataract

Based on the appearance of the cloudiness in the pupil, the cataract is classified as follows:

Senile cataract

A senile cataract has three types [4]

Subcapsular – These cataracts may be anterior or posterior. The anterior variety lies directly under the lens capsule and is associated with fibrous metaplasia of the anterior epithelim of the lens. The posterior type lies just in front of the posterior capsule and is associated with posterior migration of the epithelial cells of the lens. Patients with posterior subcapsular opacities are particularly troubled by headlights of oncoming cars and by bright sunlight. Their vision for near is also frequently diminished more than their distant vision.

Nuclear cataract - This type of cataract is an exaggeration of the normal ageing[3] change involving the pupil nucleus. It is frequently associated with myopia due to an increase in the refractive index of the nucleus and also with increased spherical aberration.

Cortical cataract – This type of cataract is one in which the opacification involves[3] the anterior, posterior or equatorial cortex .The opacities frequently assume a radial spoke like or shield like configuration and eventually the entire cortex becomes opacified.
The appearance of this type of cataract is at the periphery of the pupil.

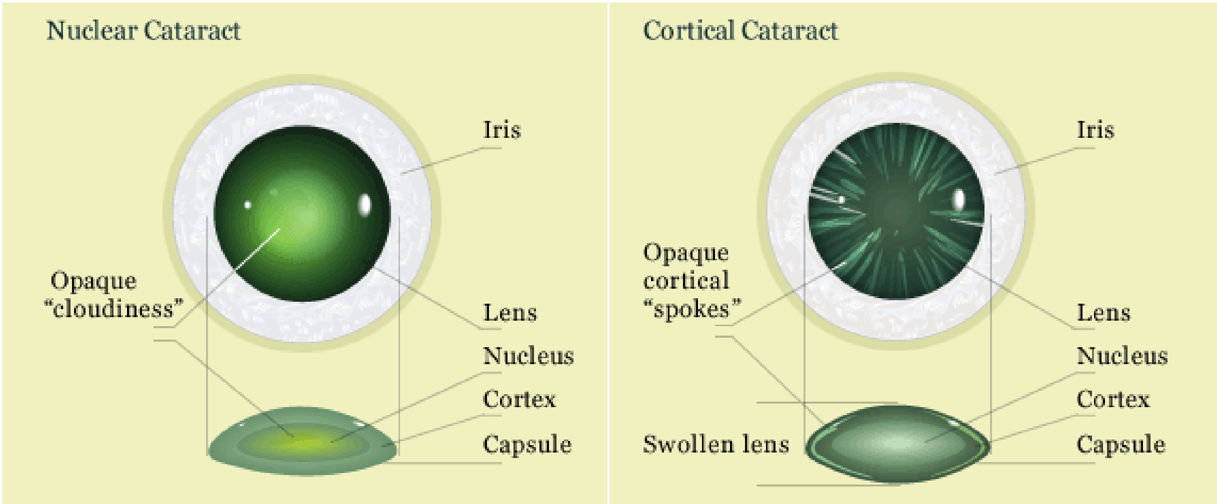


Figure 2.2: Two types of Senile cataract[4]

Traumatic[4]

This is the most common cause of unilateral cataract in young individuals[3]. Lens opacity may be due to various types of injuries e.g. Penetrating objects with direct injury to the lens may cause lens opacities.

Metabolic[4]

Diabetic cataract

Diabetes is associated with two types of cataract.

1) Senile cataract which appears earlier and may progress more rapidly in a diabetic patient than in a non - diabetic patient.
2) True diabetic cataract which is due to osmotic over hydration of the lens and appears as bilateral white punctuate or snowflake posterior or anterior opacities .

Morphological cataract[4]

Six main morphological cataract types are recognized

> Capsular

1) Posterior polar opacities as well as with pyramidal cataracts in which the opacity

[4] Available from: Jack J. Kanski, Book Clinical ophthalmology, second edition

projects into the anterior chamber

2) Acquired capsular opacities occur in pseudo exfoliation syndrome, gold toxicity, glass blowers cataract and Vossius ring

> Subcapsular

These may be posterior or anterior

1)Posterior subcapsular opacities are typical of secondary (complicated) cataracts but may also be found in associated with dystrophiamyotonica, drugs (corticosteroids), irradiation and senile (cupuliform) cataract.

2)Anterior subcapsular opacities occur in glaukomflecken, Wilson's disease and miotic therapy .

> Nuclear

1)Congenital nuclear opacities occur in Rubella in which the entire Embryonic nucleus is opaque.

2)Senile nuclear sclerosis.

> Cortical

1)Congenital cortical opacities are very common and do not usually interfere with vision. They may be white or have a deep blue hue.
A subtype of a congenital cortical opacity is a coronary cataract which surrounds the lens nucleus like a crown.

2)Senile cortical (cuneiform) cataracts start as vacuoles and clefts between the lens fibers. Opacification of the clefts leads to the formation of the typical radial spoke – like pattern which is best appreciated against the red reflex

> Lamellar

This type of opacity, which is invariably congenital, involves one lamella of the fetal or nuclear zones. Radial spoke – like opacities (riders) frequently surround the cataract

> Sutural

These are very common, congenital, Y – shaped opacities within the lens nucleus. They are of no clinical significance

In this research work, the aim was to detect only age-related cataracts which are also called as Senile cataracts and have the following types:

- Nuclear
- Cortical

2.1.2 Manual cataract detection system

A thorough eye examination through a Slit lamp by an ophthalmologist detects the presence and the extent of a cataract. If the lens of the eye appears to be cloudy, the cataract is detected. The cataract formation represents an opaque white or light blue shade on the pupil. The colour of the pupil of a normal eye is black. The cataract detection and classification can be performed on an image of a dilated pupil. The grading of cataract can be performed only on retro – illumination images i.e. lens images. These lens images are compared with the standards specified by LOCS-III. The colour intensity of the lens image is compared to a set of photographs. in LOCS-III and is graded based on its closest match with respect to the photographs.

2.1.3 Manual cataract classification system

Cataracts are detected and classified when an eye is viewed through a slit lamp. If the opaqueness is at the center of the pupil the type of cataract is Nuclear, if the opaqueness is at the periphery of the pupil the type of cataract is Cortical.

2.1.4 Manual cataract grading system

To grade a cataract to depict its advancement Slit-lamp bio-microscopy is used. The lens of an eye lies behind the pupil and is visible when Slit-lamp bio-microscopy is performed. The image of a lens which is also termed as retro-illumination image is compared with a set of standard photographs. This process is also termed as clinical grading.

Two clinical cataract grading systems are mainly used

1)Oxford clinical cataract and grading systems
2)Lens opacities classification system III (LOCS – III)

The clinical grading systems are subjective and thus they are vulnerable to in-consistencies over time and in different observers

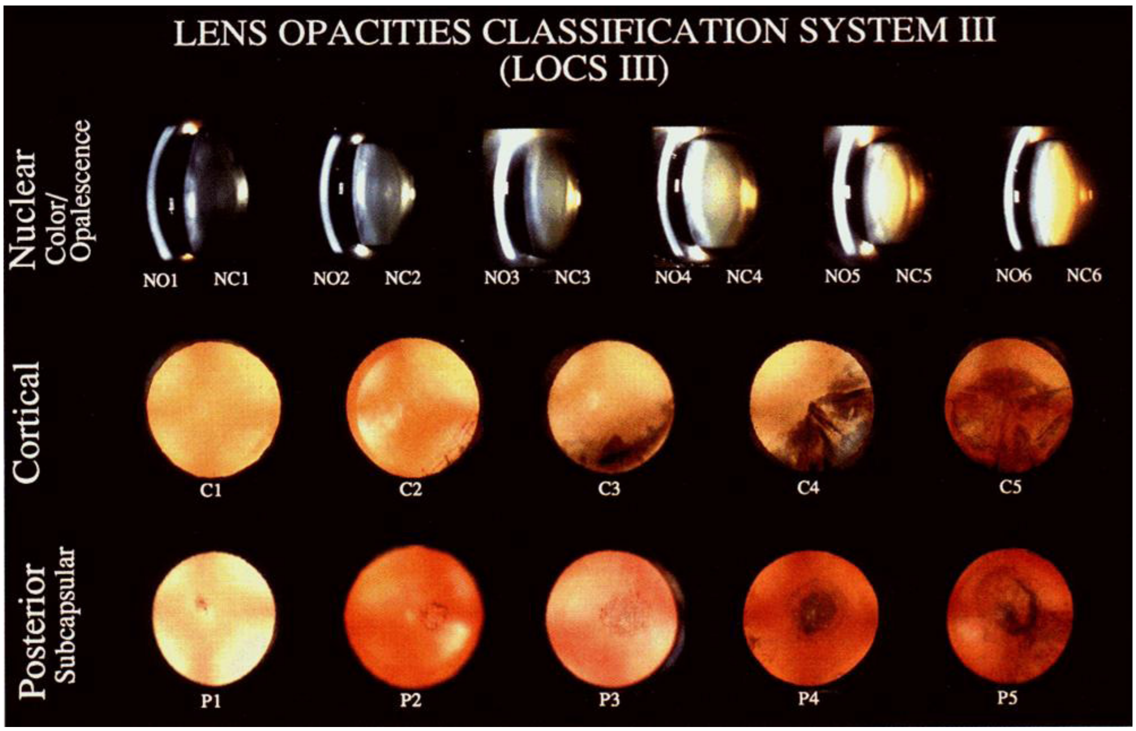


Figure 2.3: The LOCS III standards

The above figure shows five retro- illumination images for grading cortical cataract and five retro-illumination images for grading posterior sub-capsular cataract. These standard images exemplify the boundaries of scaling intervals. To grade nuclear opalescence, the average opalescence of the entire nucleus is compared with that of opalescence in each of the standard images.

2.2 Literature Survey

Cataracts can be identified by the presence of opaqueness in the lens of an image of the eye. Some successful attempts have been made for Image analysis of nuclear cataract to determine the reproducibility of densitometric measurements of the lens nucleus (Benjamin V. Magno, Valeria Freidlin and Maneul B. Datiles, 1994) A study was conducted to determine the capability of National Eye Institute Scheimpflug system in detecting changes in the nuclear region(Benjamin V. Magno, Valeria Freidlin and Maneul B. Datiles, 1995) Some successful attempts have been made for automatic grading of nuclear cataract (Huiqi Li, Joo Hweel Lim, Jiang Liu, Tien Yin Wong, 2007).
Some methods used were Support Vector Machines and Neural Network.

2.2.1 Approach based on Support Vector Machine

An Active Shape Machine was investigated for the extraction of lens contour. The color information on the central posterior subcapsular reflex was selected as the feature for grading. (Huiqi Li, Joo Hwee Lim, Jiang Liu, Tien Yin Wong, Ava Tan, Jie Jin and Paul Michell, Proc. SPIE, Vol 6915, 2008). The Support Vector Machine (SVM) scheme is proposed to grade nuclear cataract automatically.

The above research work was focused only on grading of cataract and not its detection, the assumption was that the images supplied to the system were of nuclear cataract and only nuclear cataracts were graded. The methodology followed used Support vector machines for the grading process.

2.2.2 Approach based on Fuzzy Logic

The past few years have witnessed a rapid growth in the number and variety of applications of fuzzy logic. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection.

Research based on Image classification, has demonstrated the potential usefulness of incorporating fuzziness in the training, allocation and testing stages of several classification techniques. A lot of work has been done in Fuzzy Image classification. Yannis S Avrathis and Stefanos D Kollias (2000) developed a multiresolution neural network approach to supervised classification to exploit the inherent fuzziness. In order to perform classification at different resolution levels and gain in computational complexity. In particular, multiresolution image analysis is carried out and hierarchical neural networks are used as an efficient architecture for classification of the derived multiresolution image representations. A new scheme has been introduced for transferring classification results to higher resolutions based on the fuzziness of the results of lower resolutions, resulting in faster implementation. Experimental results on land cover mapping applications from remotely sensed data have illustrated significant improvements in classification speed without deterioration of representation accuracy.

In another application the use of Fuzzy Logic was illustrated for Image edge detection(Shashank Mathur, Anil Ahlawat, 2008) the contempory Fuzzy logic helped to implement the fuzzy algorithms to find and highlight all the edges associated with an image by checking the relative pixel values in an image. An exhaustive scanning of an image using the windowing technique was subjected to a set of fuzzy conditions for the comparison of pixel values. After the testing of fuzzy conditions, appropriate values were allocated to the pixels in the window under testing to provide an image highlighted with all the associated edges.

The work in this Thesis proposed a method for detection as well as grading of cataract using Fuzzy Inference System. Grading of cortical cataract has been implemented based on the colour intensity of the images.

2.3 An Introduction to Fuzzy Logic

The real world is complex; complexity in the world generally arises from uncertainty in the form of ambiguity. Humans have the capacity to reason approximately. In reasoning about a complex system, humans reason approximately about its behavior, thereby maintaining only a generic understanding about the problem. Dr Zadeh's principle of incompatibility suggests complexity and ambiguity are co-related

“ The closer one looks at a real- world problem, the fuzzier becomes its solution (Zadeh, 1973)

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. The reason is its simplicity. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design.

Fuzzy reasoning provides a way to understand system behavior by allowing us to interpolate approximately between observed input and output situations. Fuzzy systems can implement crisp inputs and outputs, and in such case produce a nonlinear functional mapping.

Following are the reasons to use Fuzzy logic:

1) Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. The importance of Fuzzy logic lies in the "naturalness" of its approach and not its far-reaching complexity.
2) Fuzzy logic is flexible. With any given system, it's easy to wrap it or layer more functionality on top of it without starting again from scratch.
3) Fuzzy logic is tolerant of imprecise data. Everything is imprecise if a closer look is given to a problem, but more than that, most things are imprecise even on careful examination. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.
4) Fuzzy logic can model nonlinear functions of arbitrary complexity. You can create a fuzzy system to match any set of input-output data. This process is made particularly easy by techniques like Fuzzy Inference System and Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in the Fuzzy Logic Toolbox.
5) Fuzzy logic can be built on top of the experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models,

fuzzy logic lets us rely on the experience of people who already understand our system.

6) Fuzzy logic can be blended with conventional control techniques. Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.
7) Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication.

Fuzzy set theory provides a means for representing uncertainties. The underlying power of fuzzy set theory is that it uses linguistic variables rather than quantitative variables to represent imprecise concepts.

A fuzzy set is a set containing elements that have varying degrees of membership in the set. In a crisp or classical sets members would not be present in the set unless their membership was full or complete as such their membership is assigned a value of 1. But, members in a fuzzy set can also be members of other fuzzy sets on the same universe as their membership need not be complete or 1.

A Mathematical function which defines the degree of an element's membership in a fuzzy set is called membership function. The natural description of problems, in linguistic terms, rather than in terms of relationships between precise numerical values is the major advantage of this theory.

The concept of fuzzy logic is to map an input space to an output space, and the primary mechanism for doing this is a list of if-then statements called rules. All rules are evaluated in parallel, and the order of the rules is unimportant. The rules themselves are useful because they refer to variables and the adjectives that describe those variables. Before we can build a system that interprets rules, we have to define all the terms we plan on using and the adjectives that describe them.

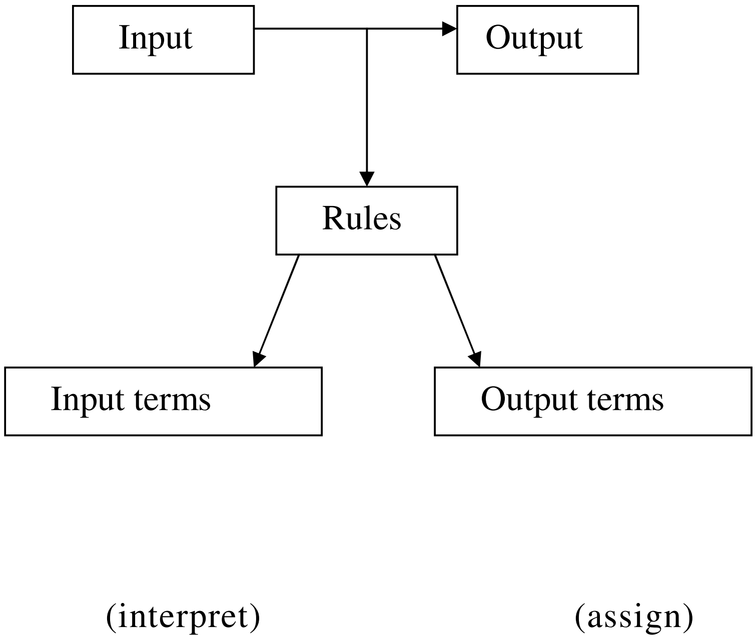


Figure 2.4: Generalized fuzzy system

Fuzzy inference is a method that interprets the values in the input vector and, based on some set of rules, assigns values to the output vector.

Control applications, such as temperature control, traffic control or process control are the most prevalent of current fuzzy logic applications.

2.3.1 Logical Operations

The most important thing to realize about fuzzy logical reasoning is the fact that it is a superset of standard Boolean logic. In other words, if we keep the fuzzy values at their extremes of 1 (completely true), and 0 (completely false), standard logical operations will hold. As an example, consider the standard truth tables below

A	B	A and B
0	0	0
0	1	0
1	0	0
1	1	1

Table 2.1: AND operation

A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

Table 2.2: OR operation

A	not A
0	0
1	1

Table 2.3: NOT operation

The min operation can be used to preserve the results obtained from the AND truth table and also extend to all real numbers between 0 and 1. This is done by resolving the statement A AND B, where A and B are limited to the range (0,1), by using the function min(A,B). Using the same reasoning, the OR operation can be replaced with the max function, so that A OR B becomes equivalent to max(A,B). Finally, the operation NOT A becomes equivalent to the operation.

The following tables illustrate the above concept.

A	B	min(A, B)
0	0	0
0	1	0
1	0	0
1	1	1

Table 2.4: AND operation

A	B	max(A, B)
0	0	0
0	1	1
1	0	1
1	1	1

Table 2.5: OR operation

A	1- A
0	0
1	1

Table 2.6: NOT operation

2.3.2 If – Then Rules

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. The if-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule is of the form if x is A then y is B, here A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The if-part of the rule "x is A" is called the antecedent or premise, while the then-part of the rule "y is B" is called the consequent or conclusion.

The following example illustrates the if- then rules

Consider people and their degree of "youth ness". In this case the set S [4] (the universe of discourse) is the set of people. A fuzzy subset YOUNG is also defined, which answers the question "to what degree is person x young?" To each person in the universe of discourse, we have to assign a degree of membership in the fuzzy subset YOUNG. The easiest way to do this is with a membership function based on the person's age.

young(x) = { 1, if age(x) <= 20,
(30-age(x))/10, if 20 < age(x) <= 30,
0, if age(x) > 30 }

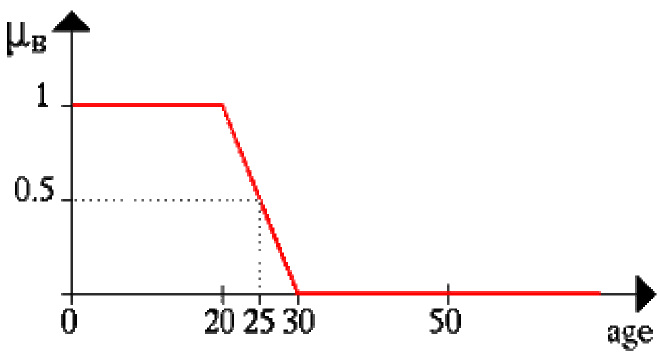


Figure 2.5: A plot of membership function based on persons age[4]

Consider the following values as an example:

Person	Age	degree of youth
A	10	1.00
B	21	0.90
C	25	0.50
D	26	0.40
E	28	0.20
F	83	0.00

So given this definition, we'd say that the degree of truth of the statement "C is YOUNG" is 0.50.

4 Available from http://www.doc.ic.ac.uk

2.3.3 Implication

Interpreting an if-then rule involves distinct parts:
1.Evaluating the antecedent which involves fuzzifying the input and applying any necessary fuzzy operators
2. Applying that result to the consequent also known as implication

In the case of two-valued or binary logic, if-then rules are easy. If the premise is true, then the conclusion is true. If the antecedent is true to some degree of membership, then the consequent is also true to that same degree. In binary logic: $p \rightarrow q$ (p and q are either both true or both false.) in fuzzy logic: $0.5\ p \rightarrow 0.5\ q$ (partial antecedents provide partial implication.)The antecedent of a rule can have multiple parts e.g.[5] if sky is gray and wind is strong and barometer is falling, then ...in which case all parts of the antecedent are calculated simultaneously and resolved to a single number using the logical operators described in the preceding section.

The consequent of a rule can also have multiple parts e.g.[5] if temperature is cold then hot water valve is 'open' and cold water valve is 'closed' which case all consequents are affected equally by the result of the antecedent. The consequent specifies a fuzzy set be assigned to the output. The implication function then modifies that fuzzy set to the degree specified by the antecedent. The most common ways to modify the output fuzzy set are truncation using the 'min' function or scaling using the 'prod' function

2.3.4 Aggregation

Since decisions are based on the testing of all of the rules in an FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. As long as the aggregation method is commutative, then the order in which the rules are executed is unimportant. Three built-in methods are supported: max (maximum), probor (probabilistic OR), and sum (simply the sum of each rule's output set).

2.3.5 Defuzzification

The method defuzzification is the conversion of a fuzzy quantity to a precise quantity. The output of a fuzzy process can be a logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variable. There are atleast seven methods for defuzzification.

Four of the most popularly used methods are as follows:[5]

1. Max-membership principle: This method is limited to peaked output functions. This method is given by the algebraic expression

$$\mu_C(Z^*) >= \mu_C(Z) \quad \text{for all } z \in Z$$

2. Centroid method: This method is also called 'center of area' or 'center of gravity' is the most commomly used method. This method is given by the algebraic expression

$$Z^* = \frac{\int \mu_{C(Z)} \cdot z dz}{\int \mu_{C(Z)} . dz}$$

3. Weighted average method: This method is only valid for symmetrical output membership function. This method is given by the algebraic expression

$$Z^* = \frac{\sum \mu_{\overline{C}(Z)} \cdot \overline{z}}{\sum \mu_{\overline{C}(Z)}}$$

where $\sum$ denotes an algebraic sum

[5] Book: Fuzzy Logic with Engineering Application by Timothy Ros

4. Mean – max membership: This method is also called 'middle of maxima' which is closely related to the first method, except that the locations of the maximum membership can be non-unique. This method is given by the expression

$$Z^* = \frac{(a + b)}{2}$$

2.4 Fuzzy Inference System

Fuzzy inference system which formulates the mapping from a given input to an output using fuzzy logic[6]. The mapping then provides a platform from which decisions can be made. The process of fuzzy inference involves all of the pieces that are described in the previous sections: membership functions, fuzzy logic operators, and if-then rules. There are two types of fuzzy inference systems namely: Mamdani-type and Sugeno-type. These two types of inference systems vary in the way their outputs are determined.

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani [Mam75] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained €from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [Zad73].

The Mamdani-type inference, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. it is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as

[6]Available from: www.mathworks.com

a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points.

The Sugeno-type systems or Takagi-Sugeno-Kang, method of fuzzy inference. introduced in 1985 [Sug85], is similar to the Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either constant or linear.

2.5 Summary

In this chapter we have reviewed the medical concepts of cataract like the different types of cataract. We began with a brief introduction about what a cataract is and their classification as Nuclear, Cortical and sub-capsular based on the appearance of cataract formation. This was followed by a discussion of Literature Survey which reviewed the different approaches used in similar Research areas. An introductory information about Fuzzy Logic was also given in this chapter. We then described the Fuzzy Inference System and its methodology followed to define membership functions, and designing rules to achieve the desired outcome.

CHAPTER 3

Research Design

3.1 Image Cropping

The aim of this work was to identify the presence of cataract in an eye image which is recorded when the eye is viewed through a slit lamp. The images included in the study comprise a portion of the face of the patient and sometimes, even the complicated background. We need to extract only the pupil portion from the image. A lens lies behind the pupil which turns opaque due to the presence of cataract. Image cropping is a technique to achieve the above.

Figure 3.1 : Original image of a subject with cataract eye

The above image includes a portion of the face and the background.
The following MATLAB functions were used to crop the image and extract the region of interest.

I2 = imcrop(I)

Here, I is the original image 'imcrop' function returns the cropped image in the supplied output argument I2.
Microsoft Picture Manager also proved to be an alternative tool for image cropping.

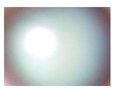


Figure 3.2: Image after cropping

The image type under the current study is an RGB image of class uint8

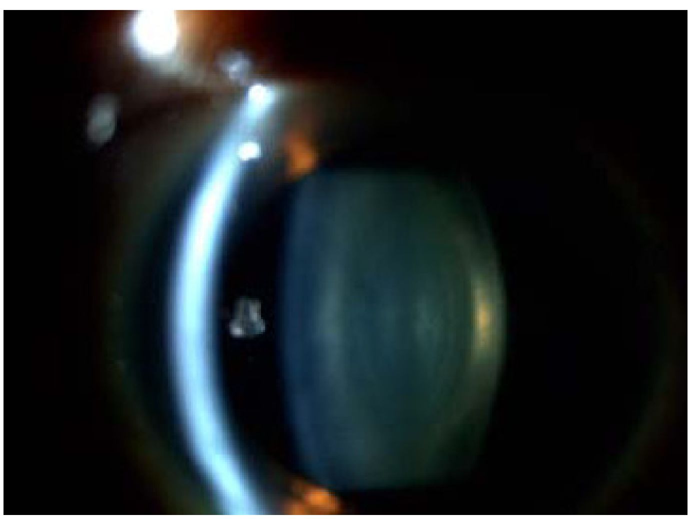


Figure 3.3 : Retro-illumination image of nuclear cataract

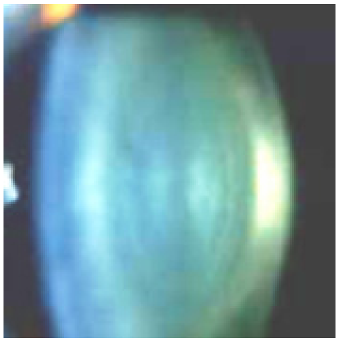


Figure 3.4 : Cropped and enhanced retro-illumination image

3.2 Image enhancement

The cropped image was enhanced using ‘stretchlim’ which finds limits to contrast stretch an image

LOW_HIGH = stretchlim(I,TOL)
LOW_HIGH = stretchlim(RGB,TOL)

The above function returns a pair of intensities that can be used by ‘imadjust’ to increase the contrast of an image. TOL=[LOW_FRACT HIGH_FRACT] specifies the fraction of the image to saturate at low and high intensities. If TOL is a scalar, TOL = LOW_FRACT, and HIGH_FRACT = 1 - LOW_FRACT, which saturates equal fractions at low and high intensities.

Using ‘stretchlim’ the image ‘I’ was enhanced by the following functions

I = imread(F:\check.jpg);
J = imadjust(I, stretchlim(I),[]);

The functions were useful for enhancing the clearity of the image.

3.3 Extract Data of Interest

The next step after image enhancement is to determine pixel colour values. The code for extracting the Red, Green, Blue values comprised of the following MATLAB function:

pixval = impixel[I, c, r]

Here, I is the image object, r and c are equal-length vectors specifying the coordinates of the pixels whose RGB values are returned in pixval. The k^{th} row of pixval contains the RGB values for the pixel (r(k),c(k)). The 'impixel' function works with indexed, intensity and RGB images, impixel always returns pixel values as RGB triplets irrespective of the image type. For an RGB image, impixel returns the actual data for the pixel. Since the image size for all the images under study is 175x175.
The c, r vectors will have values

c = [1:175]
r = [1:175]

The values returned were uint8 integers as the class of image array supplied was uint8. The Red, green and blue values were extracted and stored as three separate files.

3.4 Fuzzy Inference System Approach

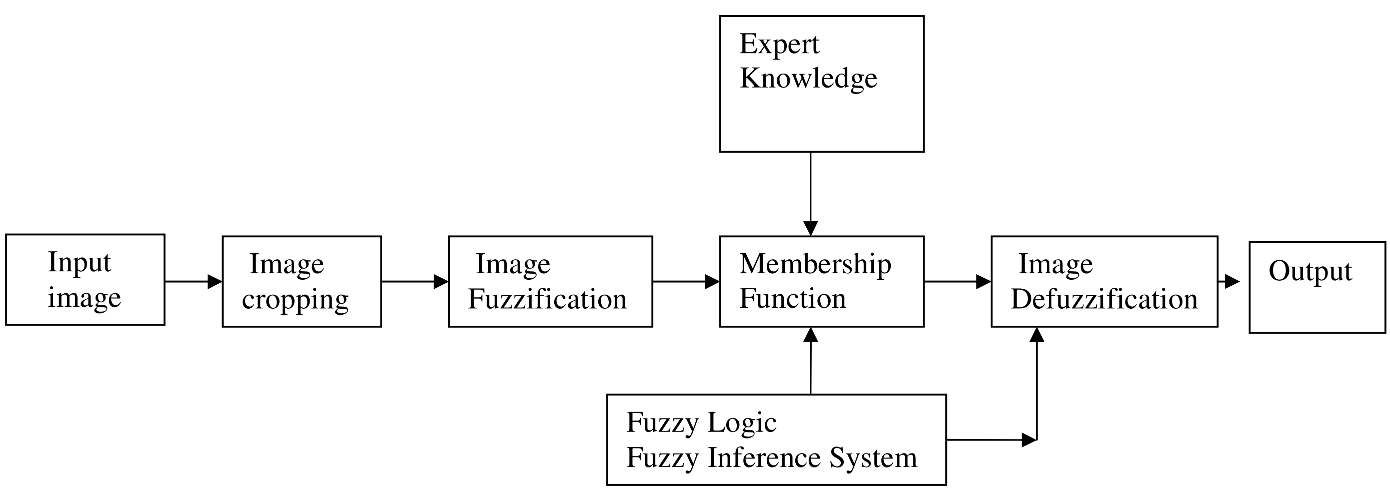


Fig 3.5: Preprocessing and Feature Extraction

In the lack of precise mathematical model which will describe the behavior of the current system, Fuzzy Logic Toolbox proved to be a good 'weapon' to solve the problem by using logical if-then rules to describe the system's behavior. This Toolbox is a compilation of functions built on the MATLAB numeric computing environment and provides tools for creating and editing 'Fuzzy Inference Systems' within the MATLAB framework.

The toolbox provides three categories of tools:

1. Command line functions
2. Graphical interactive tools
3. Simulink blocks and examples

Fuzzy Logic Toolbox allows building two types of systems:

1. Fuzzy Inference System (FIS)
2. Adaptive Neuro-Fuzzy Inference System (ANFIS)

Fuzzy Logic Toolbox was used for developing Fuzzy Inference System for

1. Defining membership functions
2. Designing fuzzy logic inference rules
3. Defuzzification

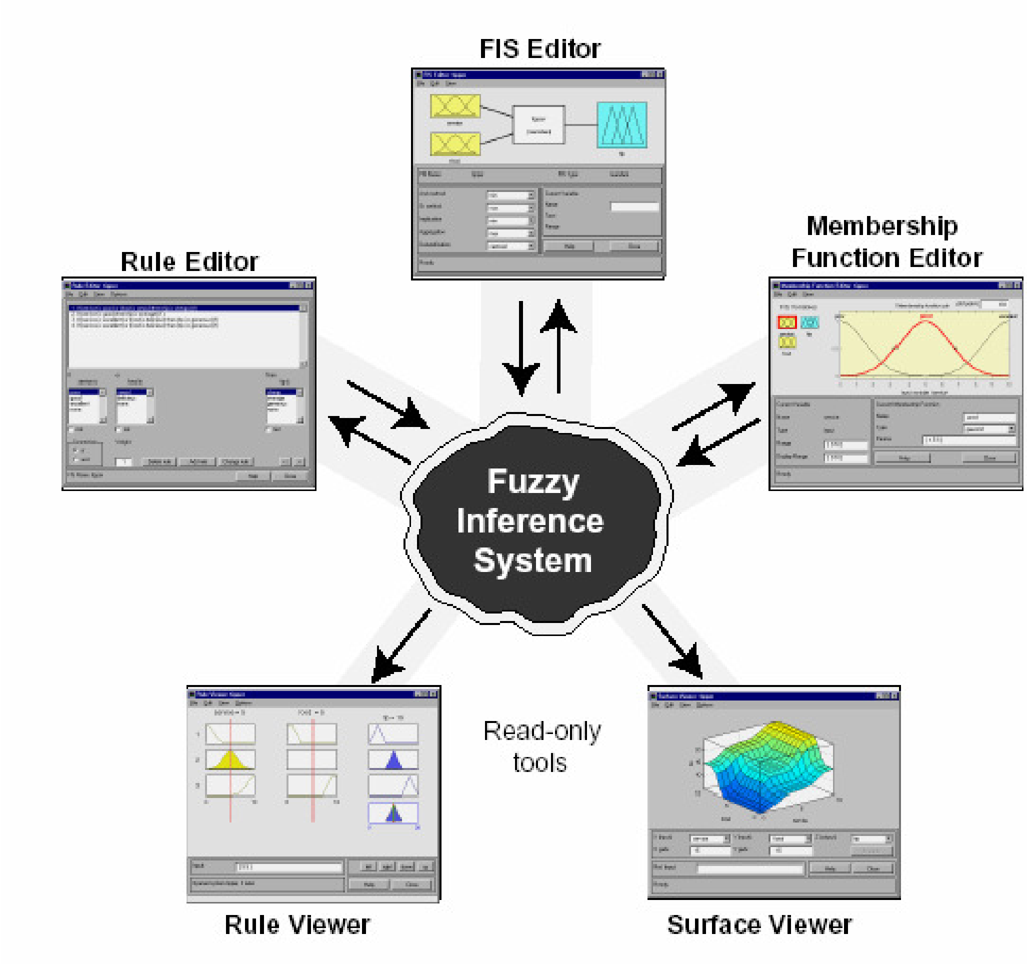


Fig 3.6: Fuzzy Inference System[6]

There are five primary GUI tools for building, editing, and observing fuzzy inference systems in the Fuzzy Logic Toolbox: the Fuzzy Inference System or FIS Editor, the Membership Function Editor, the Rule Editor, the Rule Viewer, and the Surface Viewer. These GUIs are dynamically linked, i.e. the changes we make to the FIS using one of them, can affect what you see on any of the other open GUIs. You can have any or all of them open for any given system. In addition to these five primary GUIs, the toolbox includes the graphical ANFIS Editor GUI, which is used for building and analyzing Sugeno-type adaptive neural fuzzy inference system.
Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic.

The process of fuzzy inference involves:

1) Membership functions
2) Fuzzy logic operators
3) If-then rules

There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic toolbox

1) Mamdani
2) Sugeno

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology and it expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that is needed to be defuzzified. Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant. This fuzzy inference system was introduced in 1985 and also is called Takagi-Sugeno-Kang. Sugeno output membership functions (z, in the following equation) are either linear or constant.

3.4.1 Membership Function

Membership function is the mathematical function which defines the degree of an element's membership in a fuzzy set.

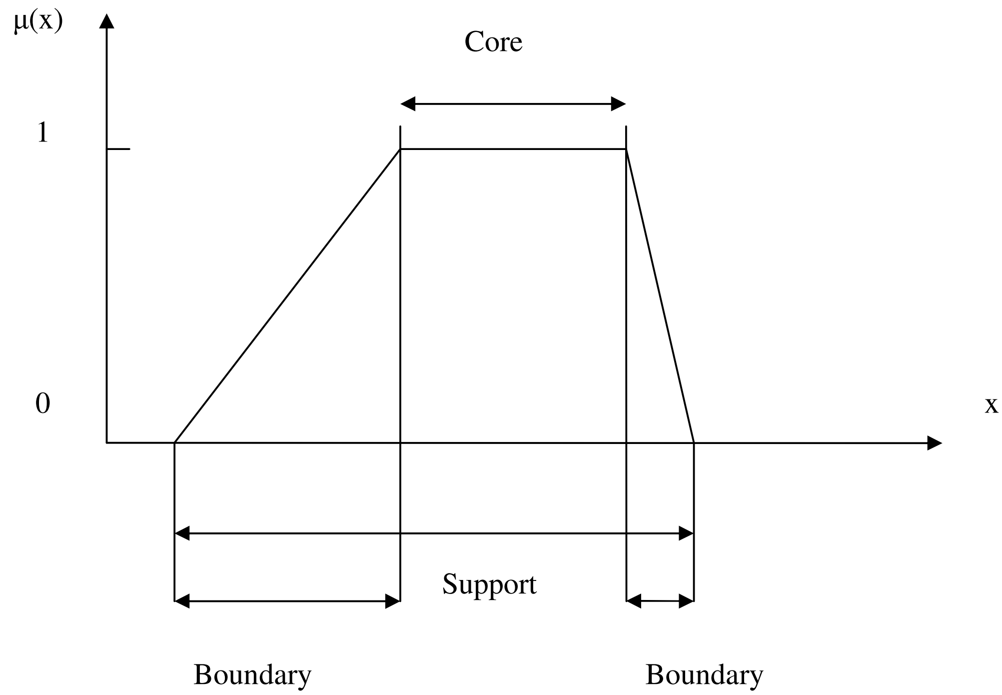


Figure 3.7 Core, Support and boundaries of a fuzzy set

The *core* of a membership function for some fuzzy set A is defined as that region of the universe that is characterized by complete and full membership in the set A. The core comprises of those elements ‘x’ of the universe such that $\mu A(x) = 1$.

The *support* of a membership function for some fuzzy set A is defined as that region of the universe that is characterized by nonzero membership in the set A. The support comprises those elements ‘x’ of the universe such that $\mu A(x) > 0$.

The *boundaries* of a membership function for some fuzzy set A are defined as that region of the universe containing elements that have a nonzero membership but not complete membership.

The Fuzzy Logic Toolbox includes eleven built-in membership function types[6]. These eleven functions are built from several basic functions: piecewise linear functions, the Gaussian distribution function, the sigmoid curve, and quadratic and cubic polynomial curves. The Membership function editor is used to display and edit all membership functions associated with all of the input and output variables for the complete fuzzy inference system. By convention, all membership functions have the letters 'mf' at the end of their names.

The simplest membership functions are formed using straight lines. Of these, the simplest is the triangular membership function, and it has the function name trimf. It's nothing more than a collection of three points forming a triangle. The trapezoidal membership function, trapmf, has a flat top and really is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity.

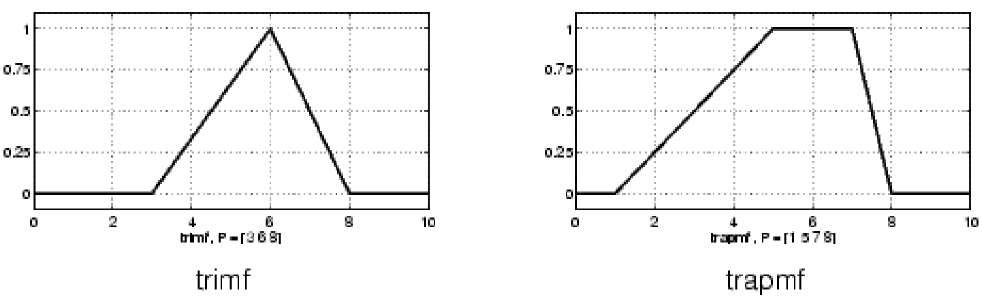


Figure 3.8 : Triangular and Trapezoidal Membership function[7]

Two membership functions are built on the Gaussian distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves. The two functions are gaussmf and gauss2mf. The generalized bell membership function is specified by three parameters and has the function name gbellmf. The bell membership function has one more parameter than the Gaussian membership function, so it can approach a non-fuzzy set if the free parameter is tuned. Because of their smoothness and concise notation, Gaussian and bell membership functions are popular methods for specifying fuzzy sets. Both of these curves have the advantage of being smooth and nonzero at all points.

[7] Available from http://www.ajes.com, also available at www.mathworks.com

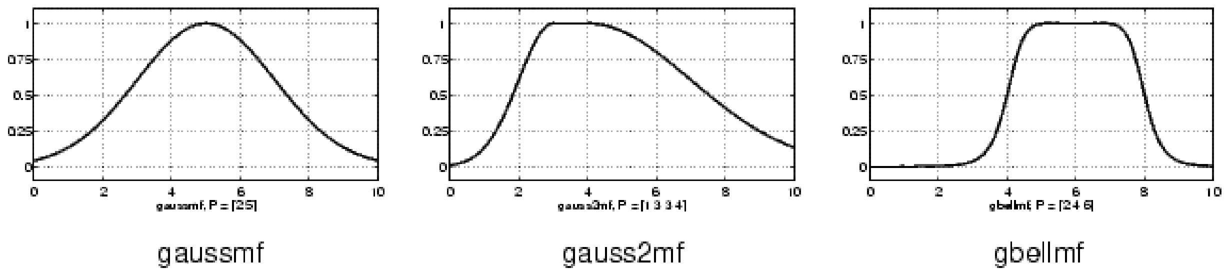


Figure 3.9: Gaussian and bell membership function[7]

Although the Gaussian membership functions and bell membership functions achieve smoothness, they are unable to specify asymmetric membership functions, which are important in certain applications.

The sigmoid membership function, which is either open left or right. Asymmetric and closed (i.e. not open to the left or right) membership functions can be synthesized using two sigmoidal functions, so in addition to the basic sigmf, we also have the difference between two sigmoidal functions, dsigmf, and the product of two sigmoidal functions psigmf.

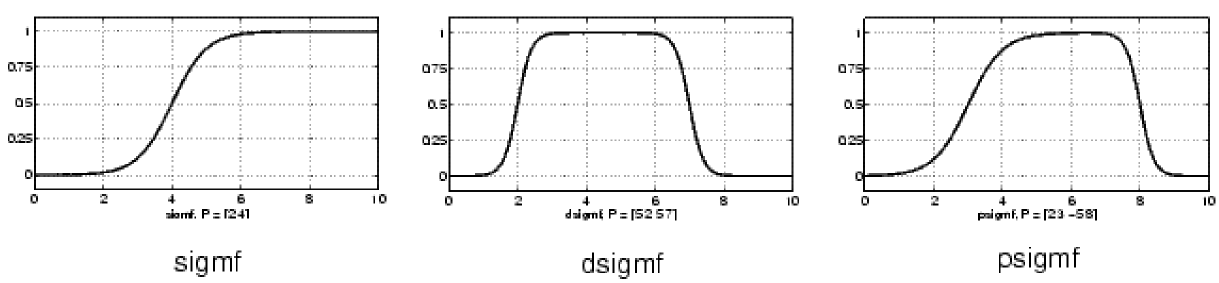


Figure 3.10: Sigmoidal membership function[7]

Polynomial based curves account for several of the membership functions in the toolbox. Three related membership functions are the *Z*, *S*, and Pi curves, all named with respect to their shape. The function zmf is the asymmetrical polynomial curve open to the left, smf is the mirror-image function that opens to the right, and pimf is zero on both extremes with a rise in the middle.

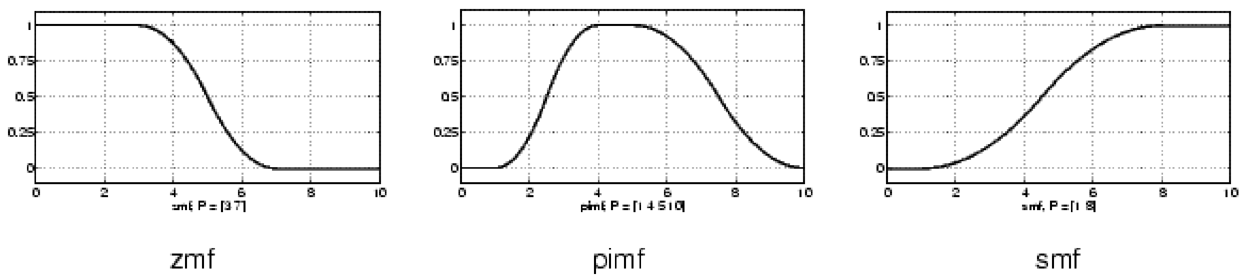


Figure 3.11: Polynomial membership functions[7]

The Fuzzy Logic Toolbox also allows us to create our own membership functions if the above list seems to be too restrictive.

In the current study, Trapezoidal membership function was used.

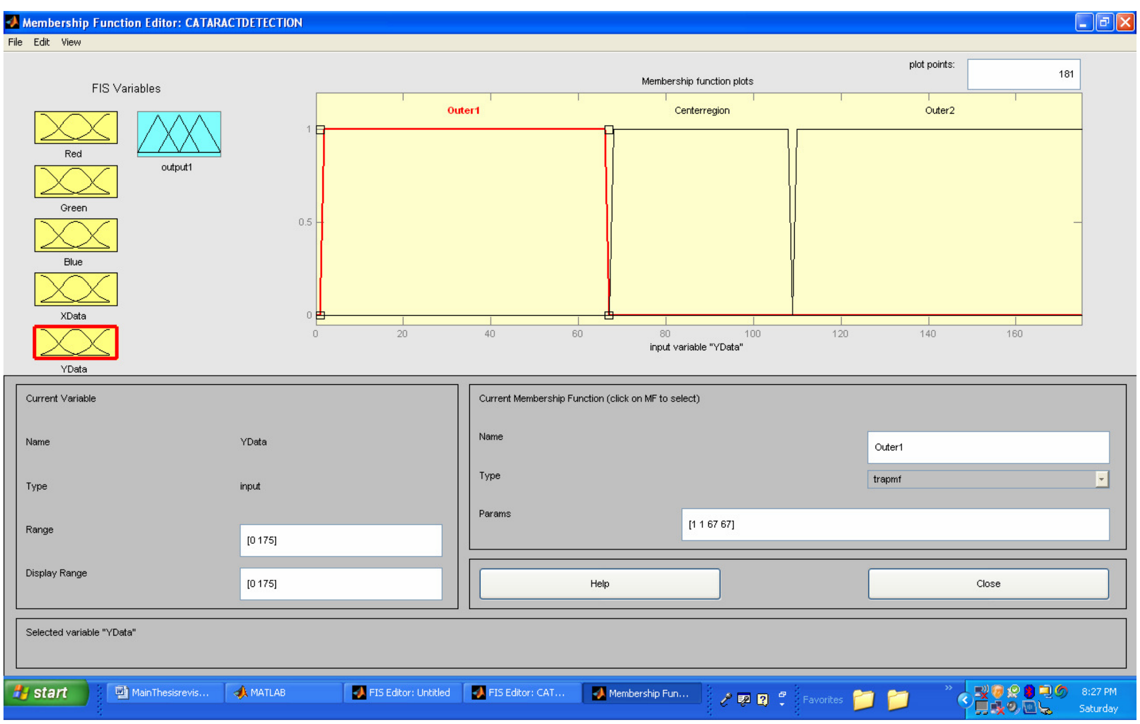


Figure 3.12: Trapezoidal membership function

3.4.2 Membership Function for Cataract Detection and classification

Trapezoidal membership function accepts four membership parameters [X,Y, Xi,Yi] here [X,Y] is the starting minimum value for the membership function, [Xi,Yi] is the maximum value for the membership function. The membership function spans over this minimum and maximum range.

Two membership functions were designed for the input Red, Green, Blue for the fuzzy Inference system

1)Input1 - If the Red value is between 0 to 100 the membership function is 'Darkshade'. If the red value is between 101 to 255 the membership function is 'Lightshade'.

2)Input2 - If the Green value is between 0 to 100 the membership function is 'Darkshade'. If the green value is between 101 to 255, the membership function is 'Lightshade'.

3)Input3 - If the Blue value is between 0 to 100 the membership function is 'Darkshade'. If the green value is between 101 to 255, the membership function is 'Lightshade'.

Three membership functions were designed for the input Xdata, Ydata

4)Input 4 – If the Xdata value is between 68 to 108 the membership function is 'centerportion '. If the Xdata value is between 0 to 67, the membership function is 'outer1'. If the Xdata value is between 109 to 175, the membership function is 'outer2'.

5)Input 5 – If the Ydata value is between 68 to 108, the membership function is 'centerportion ', If the Xdata value is between 0 to 67, the membership function is 'outer1'. If the Xdata value is between 109 to 175, the membership function is 'outer2'.

The membership function always takes values between 0 to 1

The presence of cataract is detected by the existence of pixels with white or light shades of blue, yellow, gray. A study of the RGB values of all these colours indicated that the values were lying above 100. So, rules were formulated to check if the pixel colours were lying above this threshold. Hence rule 1, 2 and 3 were framed considering the above discussion.

The size of the images under study were restricted to 175 x 175. The computation of the regions were as shown in fig. 3.13. Since the image size is restricted, the center of the image lies at location (88, 88). A study of nuclear and cortical cataract was carried out to know the location of the cataract pixels. The study put light on the fact that nuclear cataract appears at the nucleus of the lens i.e. center of the lens and may span to some radial distance from the center. The cortical cataract lies at the periphery of the lens i.e. away from the center. The 'center-region' and 'outer1' and 'outer2' were initially some arbitrary values considering certain assumptions. This was applied to several images to identify the range of co-ordinates where the cataract pixels lie for the above two predefined types of cataracts.

3.4.3 Membership Function for Grading of Cortical Cataract

The intensity of Red, Green, Blue values was computed for the five retro-illumination images represented by C1, C2, C3, C4, C5 (refer fig3.15) by cropping the images so as to identify the pure intensity shade for each grade and then identifying the maximum and minimum values for each colour ie. Red, Green, Blue

Five membership functions were designed for the three inputs

1. If Red lies in to intensity values of c1 then it represents mf 'c1'
2. If Red lies in to intensity values of c2 then it represents mf 'c2'
3. If Red lies in to intensity values of c3 then it represents mf 'c3'
4. If Red lies in to intensity values of c4 then it represents mf 'c4'
5. If Red lies in to intensity values of c5 then it represents mf 'c5'

The above five membership functions also were designed for the second and third input namely, Green and Blue based on the intensity values for Green and Blue.

3.4.4 Fuzzy Logic Operators

The Fuzzy logical reasoning is a superset of standard Boolean logic. In other words, if the fuzzy values are kept at their extremes of 1 (completely true) and 0 (completely false), standard logical operations will hold. That is, A AND M operator is replaced with minimum - min(A,M) operator, A OR M with maximum - *max* (A,M) and NOT M with 1-M. The AND operation is used to formulate rules with membership function variables for each of the inputs to the Fuzzy Inference System.

3.4.5 If-Then Rules

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic Usually the knowledge involved in fuzzy reasoning is expressed as rules in the form:

If x is A Then *y* is B

where x and y are fuzzy variables and A and B are fuzzy values. The if-part of the rule "*x* is *A*" is called the antecedent or premise, while the then-part of the rule "y is B" is called the consequent or conclusion. Statements in the antecedent (or consequent) parts of the rules may well involve fuzzy logical connectives such as ‘AND’ and ‘OR’. In the if-then rule, the word ‘is’ gets used in two entirely different ways depending on whether it appears in the antecedent or the consequent part.

3.4.6 Rule Formulation for Cataract Detection

An appearance of cataract is generally identified by white or colours with light shades. The input Red, Green, Blue are true colours of an RGB image, the input and display range is 0 to 255. These pixel colour values i.e. the Red, Green, Blue intensity values of all pixels in an image were passed as input to the Fuzzy inference system along their (X, Y) co-ordinates.

Rules were framed in the Fuzzy Sense to differentiate between different levels and shades of colors in the human perspective. Fuzzy output will differentiate between ambiguous colors. Every pixel in the image will be discriminated using fuzzy rules. The output will indicate the type of the cataract. If presence of the cataract is identified, or its absence will be indicated as non-cataract.

If the pixel colours match to ‘Lightshade’ then a cataract is detected. If the pixel colours match to ‘Darkshade’; this indicates the absence of cataract. The output from the Fuzzy Inference System is further verified by changing plots in surface viewer.

3.4.7 Rule Formulation for Cataract Classification

A cataract is classified as nuclear cataract when the appearance of the cataract is at the center of the pupil. A cataract is classified as cortical cataract when the appearance of the cataract is at the outer part of the pupil i.e. away from the center and towards the periphery.

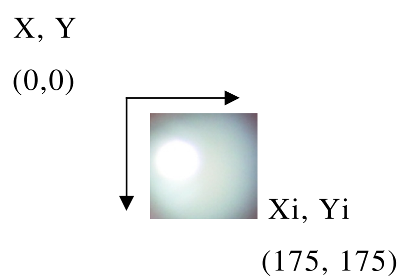


Figure 3.13 : Cropped image of a Cataract Eye

In the above figure the image is of size (175, 175). The top left corner represents the origin(0, 0) the bottom right corner indicates the max (X, Y) value (175, 175). All the images i.e regular image and retro-illumination images are restricted to a size of (175 x 175).

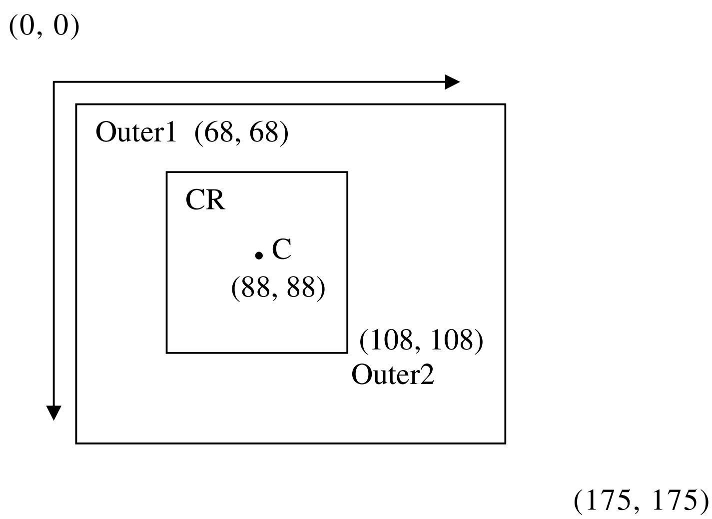


Figure 3.14: Classification of Cataract Region

In the figure, C indicates the center of the axis located at position (X,Y) = (88, 88). CR indicates the center region and is shown in the inner rectangle. The top leftmost point of the inner rectangle is (68, 68) and the bottom rightmost point of the inner rectangle is (108, 108). The center region indicates the nuclear region of an image of cataract eye. ‘Outer1’ indicates the periphery region of cataract eye. The pixels whose co-ordinates lie in the range (1,1) and (67, 67) belong to the membership function ‘Outer1’. ‘Outer1’ and ‘Outer2’ indicates the periphery region of cataract eye. The pixels whose co-ordinates lie in the range (109,109) and (255, 255) belong to the membership function ‘Outer2’

The actual membership function design to categorize the XData are as follows:

1. If XData has a value between 1 to 67, X co-ordinate lies in ‘Outer1’ region
2. If XData has a value between 68 to 108, X co-ordinate lies in ‘centerregion’
3. If XData has a value between 109 to 175, X co-ordinate lies in ‘Outer2’ region

The actual membership function design to categorize the YData are as follows:

1. If YData has a value between 1 to 67, Y co-ordinate lies in ‘Outer1’ region
2. If YData has a value between 68 to 108, Y co-ordinate lies in ‘centerregion’
3. If YData has a value between 109 to 175, Y co-ordinate lies in ‘Outer2’ region

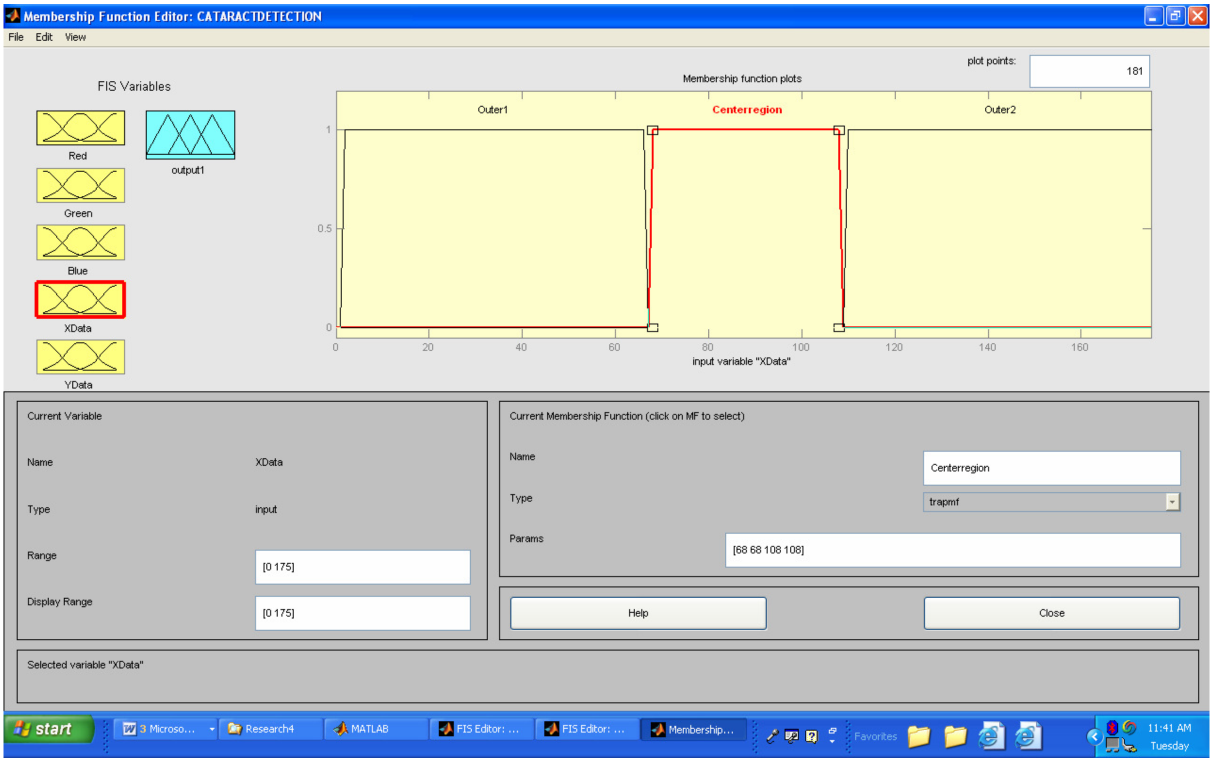


Figure 3.15: Membership function formulation for XData

To identify cataract the following rules were formulated:

- Rule 1 - If (Xdata is centerportion) and (Ydata is centerportion) and (Red is Lightshade) and (Green is Lightshade) and (Blue is Lightshade) then (output is Nuclearcataract)
- Rule 2 - If (Xdata is Outer1) and (Ydata is Outer1) and (Red is Lightshade) and (Green is Lightshade) and (Blue is Lightshade) then (output is Corticalcataract)
- Rule 3 - If (Xdata is Outer2) and (Ydata is Outer2) and (Red is Lightshade) and (Green is Lightshade) and (Blue is Lightshade) then (output is Corticalcataract)
- Rule 4 - (Red is Darkshade) and (Green is Darkshade) and (Blue is Darkshade) then (output is noncataract)

All the above rules have a weightage of '1'

It is very important to know that by medical definition even if any small opacity is encountered the cataract is detected. In the computation of 'status' of the eye even if one opaque pixel with 'light shade' is encountered the 'status' is 'cataract'.

To verify the region properties of an image the following MATLAB function was used

STATS = regionprops(L,properties)

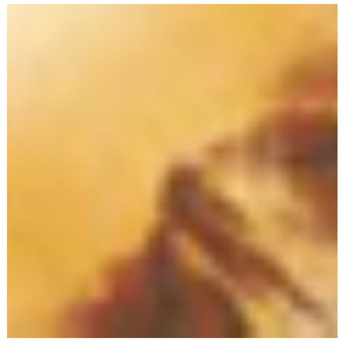
It measures a set of properties for each labeled region in the label matrix L. Positive integer elements of L correspond to different regions. For example, the set of elements of L equal to 1 corresponds to region 1; the set of elements of L equal to 2 corresponds to region 2; and so on. The return value STATS is a structure array of length max(L(:)). The fields of the structure array denote different measurements for each region, as specified by properties. The'Centroid' property can be used to check center of mass,

'Centroid' is a one-by-ndims(L) vector, and represents the center of mass of the region.

3.4.8 Rule formulation for Grading of Cortical Cataract

Grading of cataract can only be done on retro-illumination images. The lens of an eye which lies behind the pupil can be viewed in a retro-illumination image. The lens colour is compared with the images in LOCS-III (refer fig 2.2) and is graded based on the colour it closely matches too.

C1 C2



C3 C4

C5

Figure 3.16: Cropped retro-illumination images of cortical cataract representing grade C1, C2, C3, C4, C5

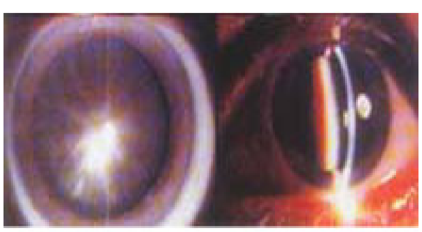


Figure 3.17: Slit Lamp image of a nuclear cataract (left) and its retro-illumination image (right) [8]

The above figure shows the two types of images captured through a slit-lamp.

[8] Available from http://www.myeyeworld.com

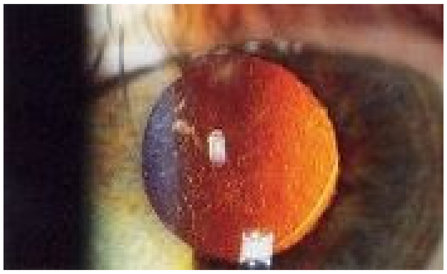


Figure 3.18: Slit Lamp image of a cortical cataract [8]

The pixel colours are extracted and their minimum and maximum range is computed for each of the gradings c1, c2, c3, c4, c5. This is passed to a separate Fuzzy inference System developed for 'grading' cataract. This FIS has membership functions which represent these five regions, the input to this system is the Red, Green and Blue values of a retro-illumination image. The system then applies the rules in the fuzzy sense i.e with human perspective to grade the cataract into one of its five grades.

3.4.4 Aggregation and Deffuzzification

The method defuzzification is required to convert a fuzzy quantity to a precise quantity. The deffuzzification method used in the current study is 'centroid'.
algebraic expression

$$Z^* = \frac{\int \mu_{C(z)} \cdot z\,dz}{\int \mu_{C(z)} \cdot dz}$$

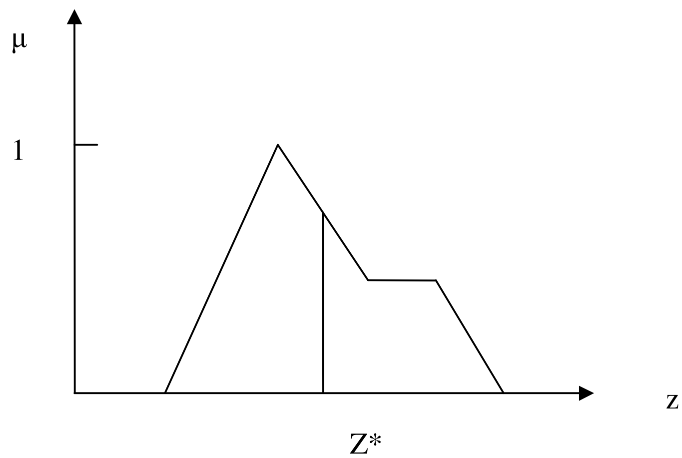


Figure 3.19: Centroid defuzzification method

3.5 Summary

In this chapter, we have presented the details of how an image is cropped and enhanced for clarity. It also explains how data of interest is extracted from an image. The Fuzzy Inference System approach to design membership functions and Rules for cataract detection and classification is explained in detail. The method used for grading of cataract using retro-illumination images is also explained along with its Rule Formulation.

CHAPTER 4 - Data Generation

4.1 Data Collection Method

The data generation method used for this Research was Observation and Recording. The data required for cataract detection was the cataract eye images which were collected from the OPD of H.V Desai Hospital, Mohammed Wadi, Pune and Ganga Clinic, Pune. The images were recorded on a digital camera when the eye was viewed through a slit lamp. A total number of 52 images were collected for the study. The original size of the images collected were 2272 x 1704. The type of the images were ‘jpg’.

This part of the Research was an Overt Research, as the fact of observation taking place was known to all the patients whose eye images were being recorded.

A schedule was prepared for the Observation which was as follows:

Date: Observer:

Sr. No	Name of Patient	Age	Operated for cataract before (Y/N)	Type of cataract detected

Table 4.1: Schedule for data collection

The data being collected was used to study which type of cataract is often developed by people in a specific age group. The type of the data collected is Qualitative data which includes the collection of two types of images of the eye when viewed through a slit-lamp

1) Normal view of eye – 52 images

2) Retro-illumination view - 10 images

4.1.1 Data Analysis

To begin identifying key themes in the data the following segments were considered

1) Segments that bear no relation to the overall research purpose so are not needed eg: the area around the eyes, background of the image.
2) Segments that provide general descriptive information that is needed in order to describe the research context eg: relation between age and cataract type detected.
3) Segments that appear to be relevant to your research eg: pupil in the eye image

The images used are non-textual qualitative data, for this type of data we need to get all the Research material into a form which is ready for analysis.
The image type was 'jpg', 'png' and belonged to the class of 'uint8'.

4.1.2 Selection of subjects

The people who were being examined at the OPD for cataract were selected for study and their eye images were recorded.

4.2 Data pre-processing

The images collected were RGB images, sometimes referred to as a true-color image, it is stored in MATLAB as an m-by-n-by-3 data array that defines red, green, and blue color components for each individual pixel. The color of each pixel is determined by the combination of the red, green, and blue intensities stored in each color plane at the pixel's location. An RGB array can be of class double, uint8, or uint16. The images under study were of class uint8. The three color components for each pixel are stored along the third dimension of the data array.

The image acquired by the data collection method (4.1) comprised of regions including portion of the face and sometimes included the complex background. Data pre-processing was required to eliminate such noise which could affect the accuracy of the system. The images were cropped and only the portion of the pupil was extracted from the image , the colour of the pixels was identified and stored in a data file using MATLAB functions .

I2 = imcrop(I)
here, I is the original image and I2 is the cropped image

I2 = imcrop(I, rect)
here, I is the original image and I2 is the cropped image, rect is a four-element vector with the form [xmin, ymin, width, height] these values are specified in spatial coordinates.

The cropped image is of size 175 x175 and belongs to the class uint8. MATLAB functions like ‘impixel’ are applied to extract the RGB values for the corresponding pixel co-ordinates in that image. These RGB values are supplied as input to the Fuzzy Inference System.

4.3 Summary

This chapter gives light on the method used for data collection, the type of data collected and the source of data collection. It also explains the pre-processing method used to extract the data of interest.

The images were collected from the Outdoor Patient Department of H.V Desai Hospital, Mohammed Wadi, Pune. The images comprised not only of the cataract eye but also included complex background and portion of the face. Hence, there was a need to extract only the region of interest required for the current study.

CHAPTER 5

Results and Conclusion

5.1 Performance of cataract detection algorithm

The basic algorithm for cataract detection works as follows

Algo Detect (Image img)

{

1. Accept image
2. Pre-process image
3. Extract region of Interest
4. Extract pixel colours
5. Identify pixels whose colour matches with shades of cataract
6. Detect cataract
7. Classify it into one of the two types
8. stop.

}

In the present work , Forty seven eye images with presence of cataract and five images with absence of cataract were tested on a system developed using the above crude algorithm

$$\text{Accuracy} = \frac{\text{Total number of images correctly classified}}{\text{Total number of images supplied to the system}} \times 100$$

Only thirty nine out of fifty two images were classified correctly. Therefore, percentage accuracy was only 75 %

Following were the reasons identified for low system accuracy:

1) The algorithm could not span accurately for considering the range of pixel colours along with classification based on pixel co-ordinates.
2) Neighbourhood pixel colours were not considered for verifying the results

5.2 Performance of cataract detection and classification using Fuzzy Inference System

The Fuzzy Inference system approach proved to be very efficient due to the following reasons:

1) The 'naturalness' in the approach to classify colours into its light and dark shades proved to be very useful and more practical.
2) The easy way to formulate rules using 'and', 'or' operators allowed to check more conditions which in turn increased the preciseness of the result.
3) More rules could be easily added and existing rules could be modified to improve accuracy of the system.
4) A wide range of Membership functions were available. The membership function best suited for the current application 'trapmf' was selected.
5) The Rule viewer proved to be a very important 'tool' to test the execution of each Rule and membership function plot for a given set of input.
6) A surface plot provided a graphical view of the output.

When an image is cropped, the shape of the cropped image is a square, the cropping was done such that the boundary of the pupil is enclosed in the cropping rectangle. Some portion of the iris is also visible at the four corners of the square. The initial FIS worked with high accuracy for images with black or brown iris. But when cropped images with blue iris were passed as input, the outcome was 'cortical' cataract. To correct this problem the membership functions were re-designed and rules were re-formulated to identify the blue and green iris as 'noncataract'. The maximum number of pixels qualifying for a output variable is considered as final output. The performance of the FIS was high .

Out of the fifty two images supplied fifty images were correctly classified. Hence System performance was increased to 96 %

It is important to know that for identifying ‘nuclear’ and ‘cortical’ cataracts a normal image of an eye when viewed through a slit lamp is sufficient for analysis. But grading of cataract can only be done on retro-illumination images.

5.3 Performance of grading of cortical cataract

This FIS works on pixel colours of retro – illumination images. This FIS was tested on pixel colours of retro-illumination images. There is very little difference between the shades represented as C1, C2, C3,C4, C5. The system works with average accuracy.

5.4 Testing accuracy of basic algorithm

The accuracy of the basic algorithm was tested manually by supplying a known image i.e. cataract or non-cataract image and comparing the result with known output. The basic algorithm works by accepting the pixel colour values and classifying the pixels based on its colour as cataract or non-cataract. But, the algorithm cannot easily span over all the shades of colours with flexibility.

5.5 Testing accuracy of Fuzzy Inference System

Fuzzy inference system provided some in-built tools which could be used to verify the result. The Rule viewer was used to test the formulation of the rule. Surface viewer provided a plot to compare any two inputs given to the system. ‘evalfis’ was used to perform fuzzy inference calculations.

output= evalfis(input, fismat)

[output, IRR, ORR, ARR]= evalfis(input, fismat)

[output, IRR, ORR, ARR]= evalfis(input, fismat, numPts)

Here, input is a matrix specifying input values. If input is an M-by-N matrix, where N is number 5 input variables and M is the number of input rows then evalfis takes each row as an input vector and returns the M-by-L matrix to the variable, output, where each row is an output vector and L is the number of output variables.

The range labels for evalfis are as follows:

input - is a number or a matrix specifying input values. If input is an M-by-N matrix, where N is number of input variables, then evalfis takes each row of input as an input vector and returns the M-by-L matrix to the variable, output, where each row is an output vector.

output - the output matrix of size M-by-L, where M represents the number of input values specified above

L - is the number of output variables for the FIS,

fismat - an FIS structure to be evaluated

The following are optional range variables

IRR - the result of evaluating the input values through the membership functions. This is a matrix of size numRules-by-N, where numRules is the number of rules, and N is the number of input variables

ORR - the result of evaluating the output values through the membership functions.

ARR - the numPts-by-L matrix of the aggregate values sampled at numPts along the output range for each output.

A bar plot of the RGB values of an image of size 175 x 175 can also help in checking the accuracy of the system.

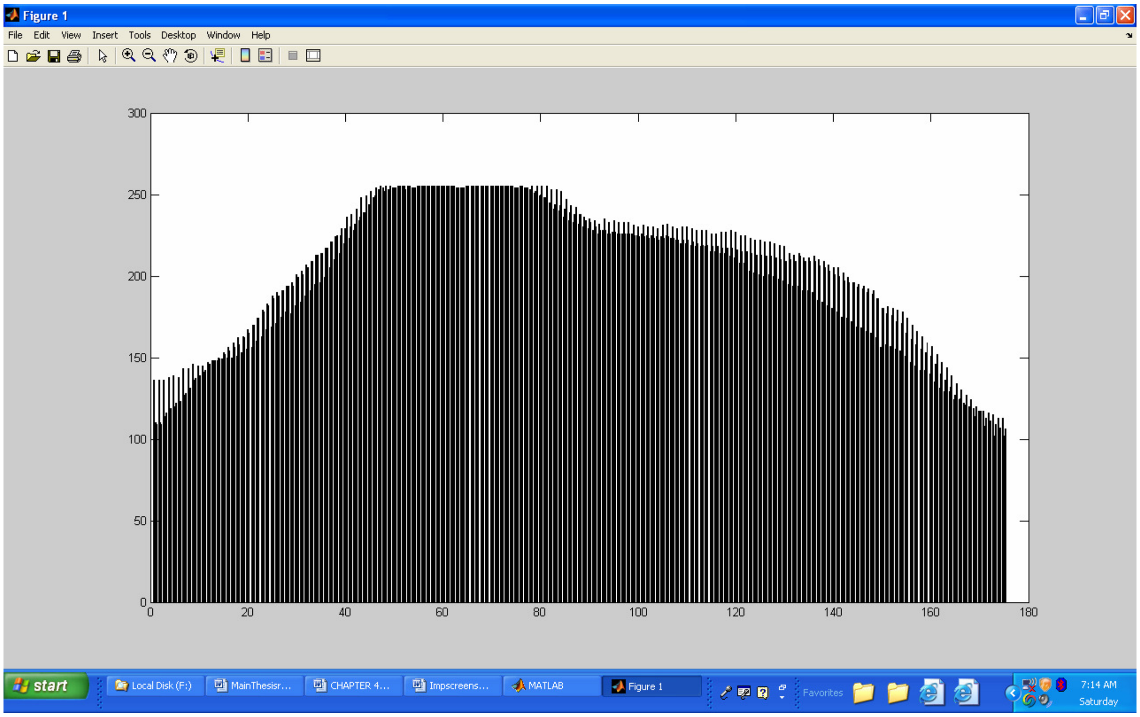


Figure 5.1: A bar plot of RGB values

The above bar plot was plotted for a cataract eye image, the plot indicates that most of the RGB values are above 100 hence the output from the FIS is verified.

A surface plot also helps to understand the distribution of RGB values

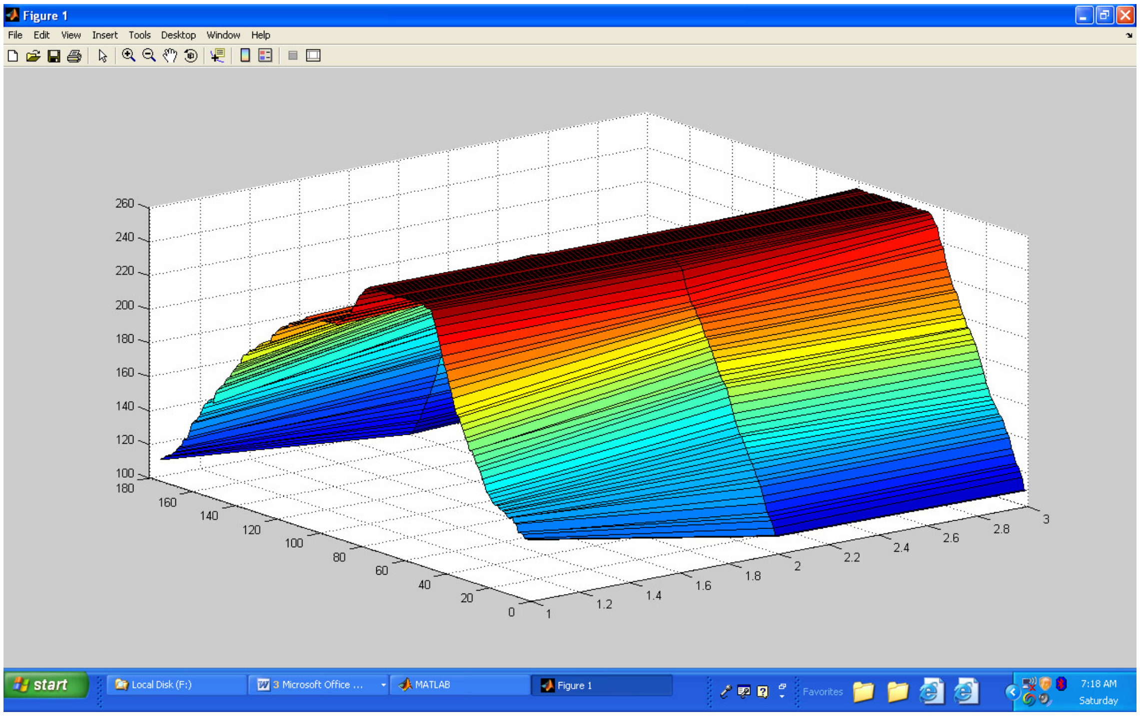


Figure 5.2: A Surface plot of RGB values

The above figure shows a 3-D surface plot of RGB values which provides a view of the distribution of RGB values on the three dimensional axis.

5.6 Conclusions

The results were verified and system performance was analyzed.

5.6.1 Aims and Motivation

The research work in this thesis is aimed at presenting and evaluating a system for cataract detection and classification which will remove the subjectivity in the current manual method and avoid the existence of an expert (surgeon) for cataract detection and classification, thus relieving him to do other important task like surgery.

Almost 70 % of the people in the world are infected by this condition. Which means that there is a high number of population who undergoes the cataract detection process.

An ophthalmologist manually compares the image viewed through a slit lamp with the standard images in LOCS-III. The fact that the clinical detection and grading systems are subjective and are vulnerable to inconsistencies over time in different observers led to a thought of automating this manual process.

5.6.2 Research Review

The application of Image processing techniques on bio-medical images for disease detection has gained importance due to its support for mathematical and knowledge based models. This research work involves the use of knowledge-based fuzzy inference system. These systems are capable of imitating the thought process and behavior of a human expert. In chapter 1 an introduction about cataract and its types is mentioned.

The literature on Opthalmology is vast, but there have been no previous efforts to abstract and document the Computer based techniques used to detect and classify eye disorders. In chapter 2, an attempt has been made to document the different approaches followed for detection and grading of eye disorders with the knowledge base in clinical ophthalmology.

The design presented in chapter 3 is based on Fuzzy Inference System, it began with extracting the data of interest, passing it as input to the FIS, formulation of membership functions and rules to get the desired outcome. A description of grading of Nuclear cataract was also included in this chapter.

The data collected for this research work was pre-processed and sent as input to the FIS. Chapter 4 gives the details of the source of data and the preprocessing method followed for generating data of interest for the current application.

The performance of the FIS and the crude approach are compared and the results are summarized in Chapter 5.

5.6.3 Contributions of the Research work

This research work was aimed at contributing to the medical facilities provided for the public.

An ophthalmologist is always consulted for eye examination when blurring of vision occurs. An attempt was made to semi-automate the detection of cataract. Thus, relieving the expert to perform more promising task like cataract surgery.

5.6.4 Comparison with related work

The concept of extracting features from bio-medical images is a new concept, there have been several prior efforts to identify and capture region of interest from these images. There have been prior efforts to detect the Iris portion in an eye image using. Ada-Boost and Neural Network (Zhong Bo Zang, Ping Zuo, Jie Ma, 2005) they developed an instrument for capturing the eye image and localizing the Iris in the captured image. There have been successful attempts to construct a simple, computer-based, quantitative surgical keratometer to measure a 3.0 to 4.0 mm central region of the corneal surface(L. Carvalho, Journal of Cataract & Refractive Surgery Vol 25 ,pp 821 - 826)

The main problem faced in automating the cataract detection was localizing the lens region. Objective quantification of lens images is very essential for cataract assessment and treatment (Huiqi Li, Joo Whee Lim, Jiang Liu, Tien Wong) presented a bottom-up and top-down approach to detect the lens contour from the slit-lamp images. The average intensity inside the lens is employed as the indicator of nuclear opacity.

My research work focuses on extracting the pupil portion from an eye image and applying image preprocessing techniques supported by MATLAB7. The resultant image is processed to extract RGB values which are then supplied as input to the Fuzzy inference system.

Rules were framed in the Fuzzy Sense to differentiate between different levels and shades of colors in the human perspective. Fuzzy output differentiates between ambiguous colors. Every pixel in the image will be discriminated using fuzzy rules. The output will indicate the type of cataract if presence of cataract is identified, or its absence is indicated as non-cataract.

5.6.5 Future work

The research work in this thesis was aimed at presenting a system for Detection and Classification of cataract eye images. Similar techniques can be applied on other bio- medical images for detection of tumors. The workload of radiologists could be halved by using a computer-aided system to help extract and classify the features of a tumor to detect cancer. Hence, only one operator will be needed to look at the results, rather than the usual two. Thus relieving the expert from reading and analyzing results.

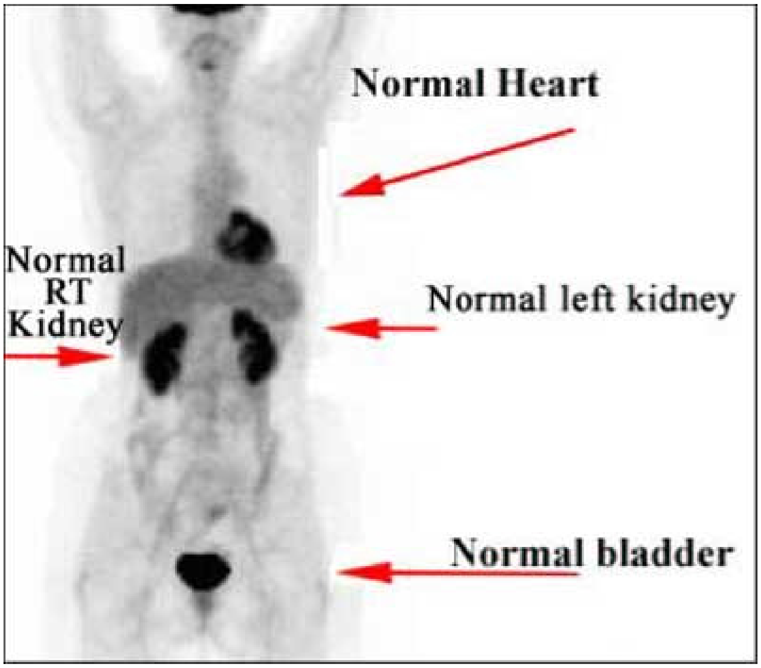


Fig 5.3: Image - Normal PET Scan

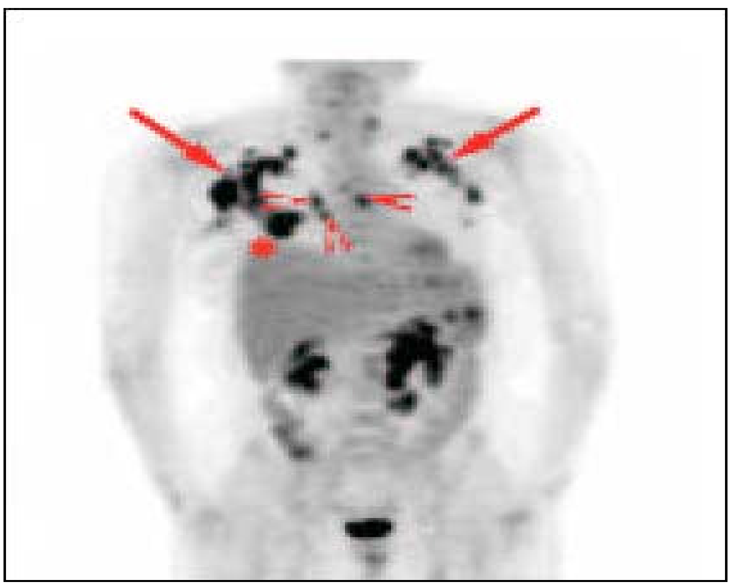


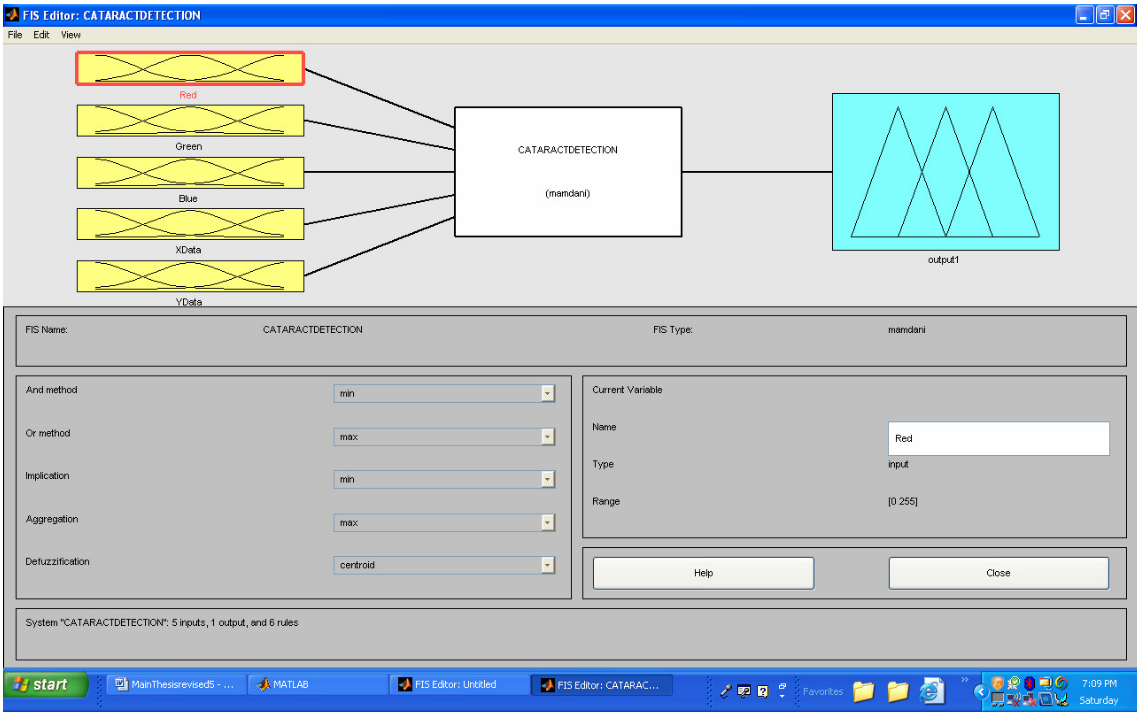
Fig 5.4 : PET scan showing abnormal lymph nodes

In the above figures, Fig 5.3 shows Normal PET Scan and Fig 5.4 shows abnormal lymph nodes. A comparison between the two figures could put light on special features which indicate the presence of abnormal lymph nodes.

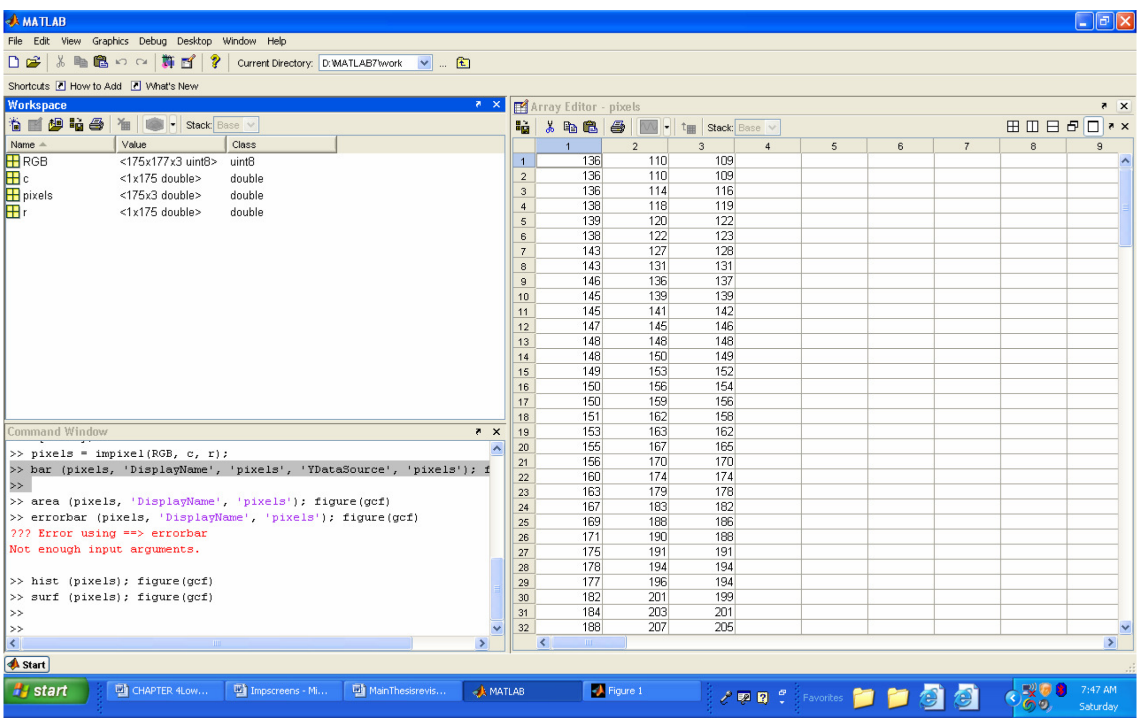
A study of abnormal lymph nodes can be performed on the following lines

1. The approximate size of abnormal lymph nodes
2. The location of abnormal lymph nodes in a scan

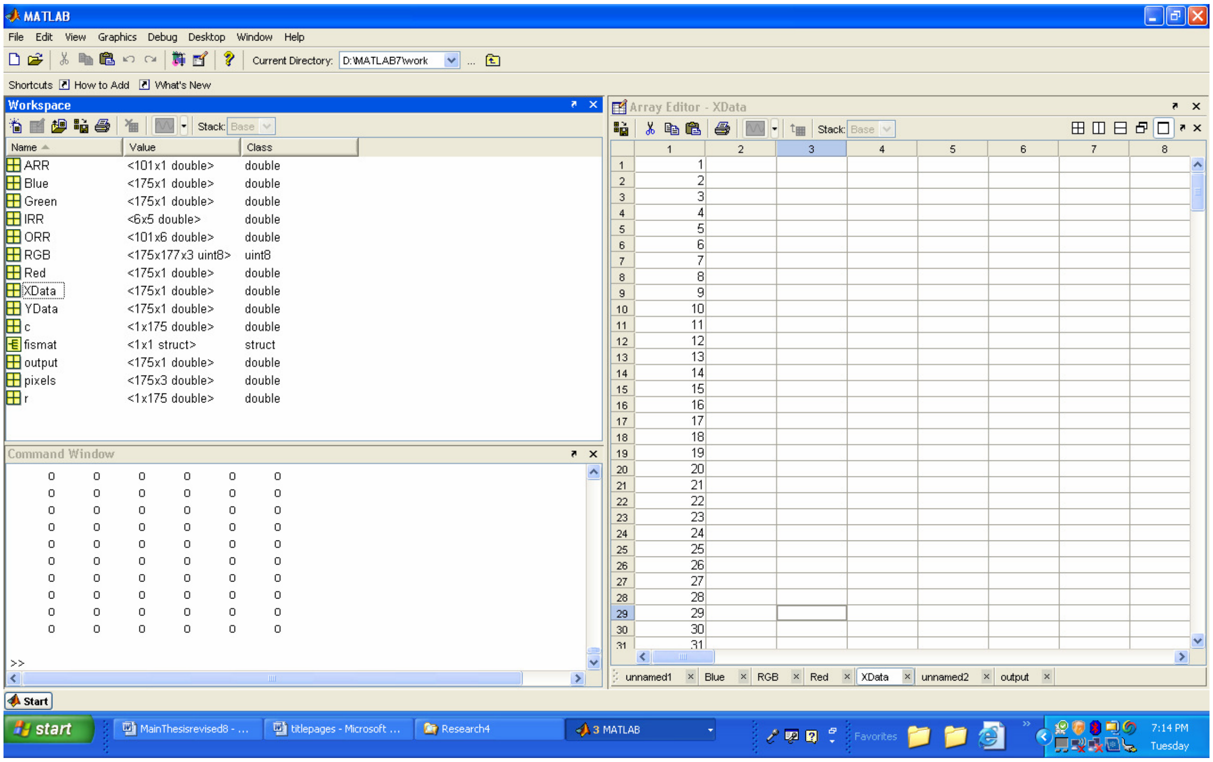
Appendix A - Screen shots



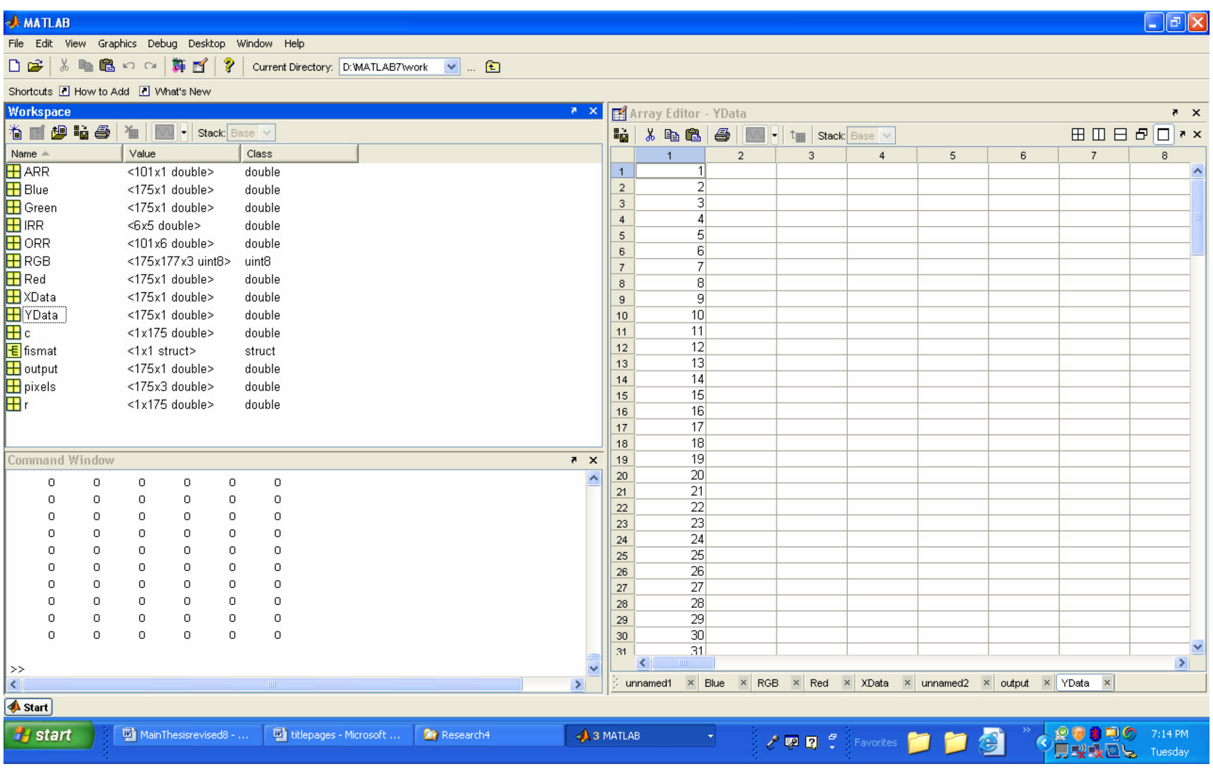
Screen 1: Cataract Fuzzy Inference System



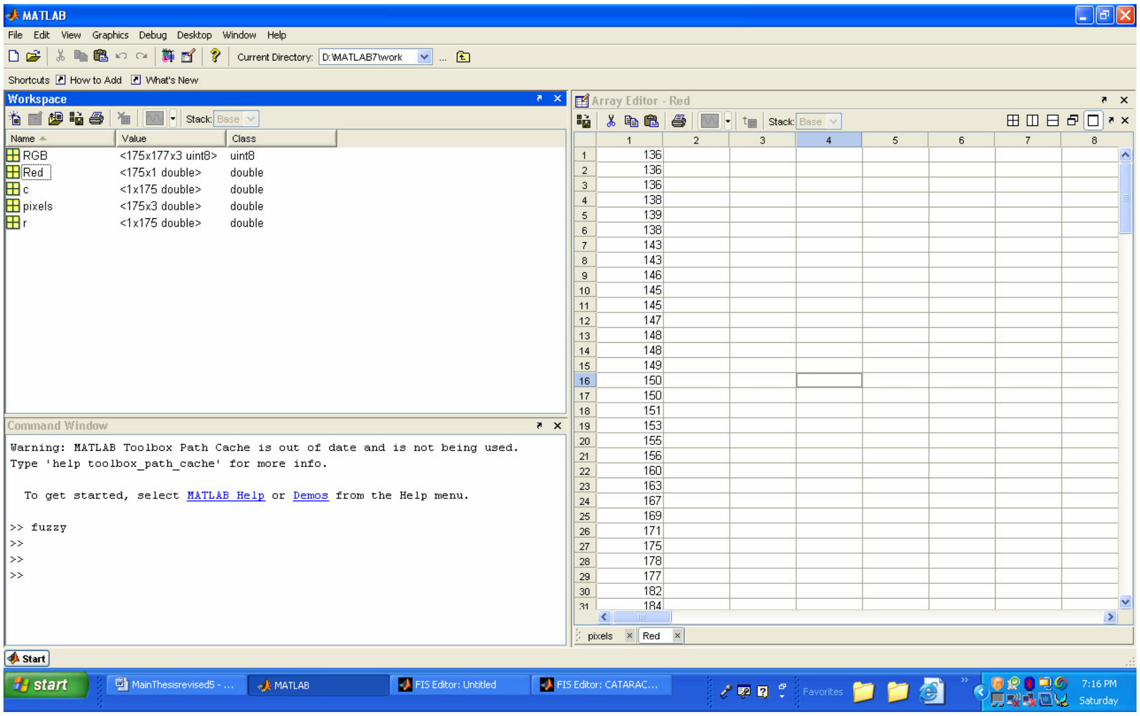
Screen 2: RGB data for an image



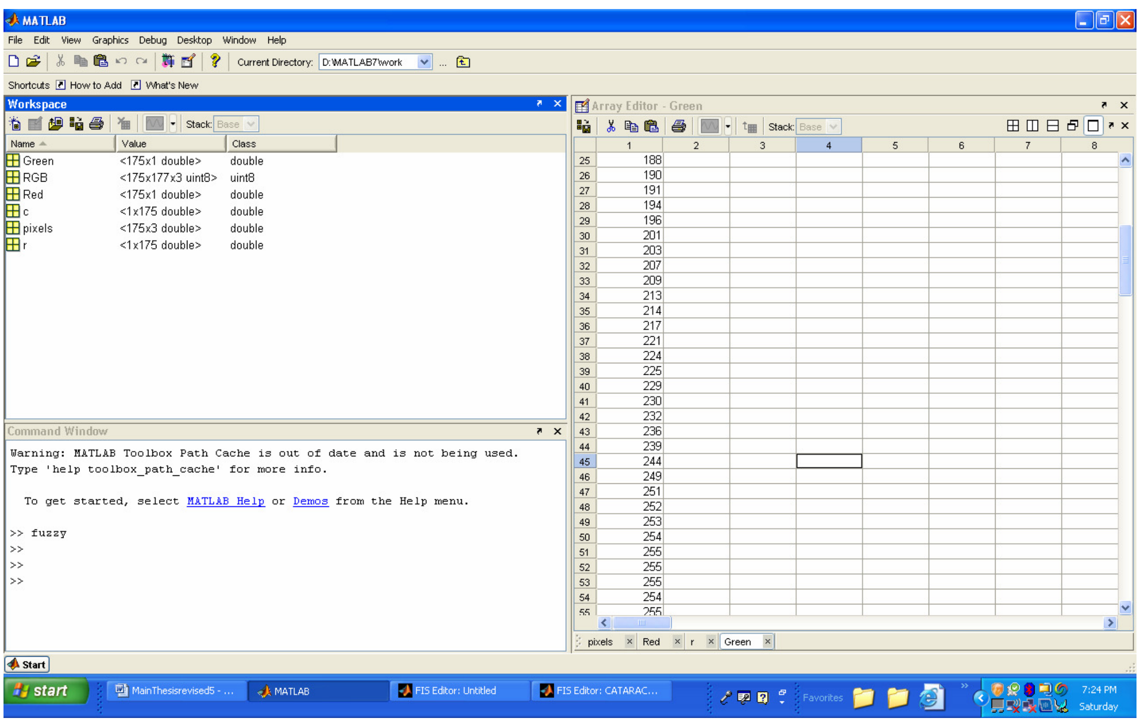
Screen 3: Xdata for an image



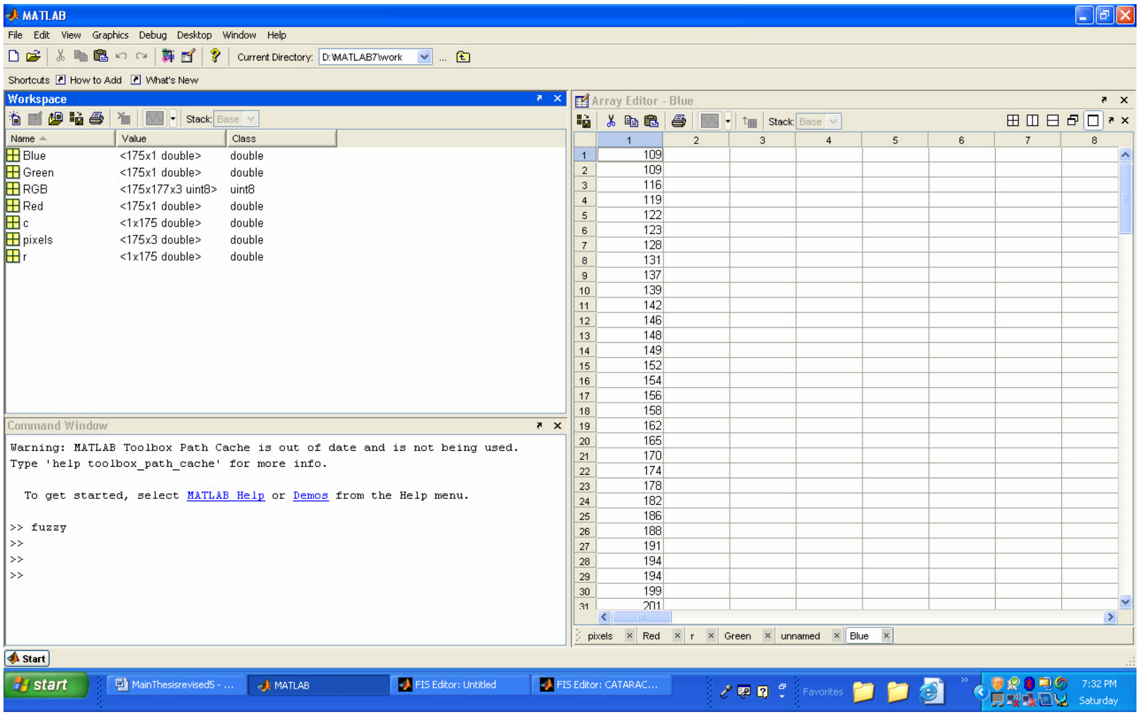
Screen 4: Ydata for an image



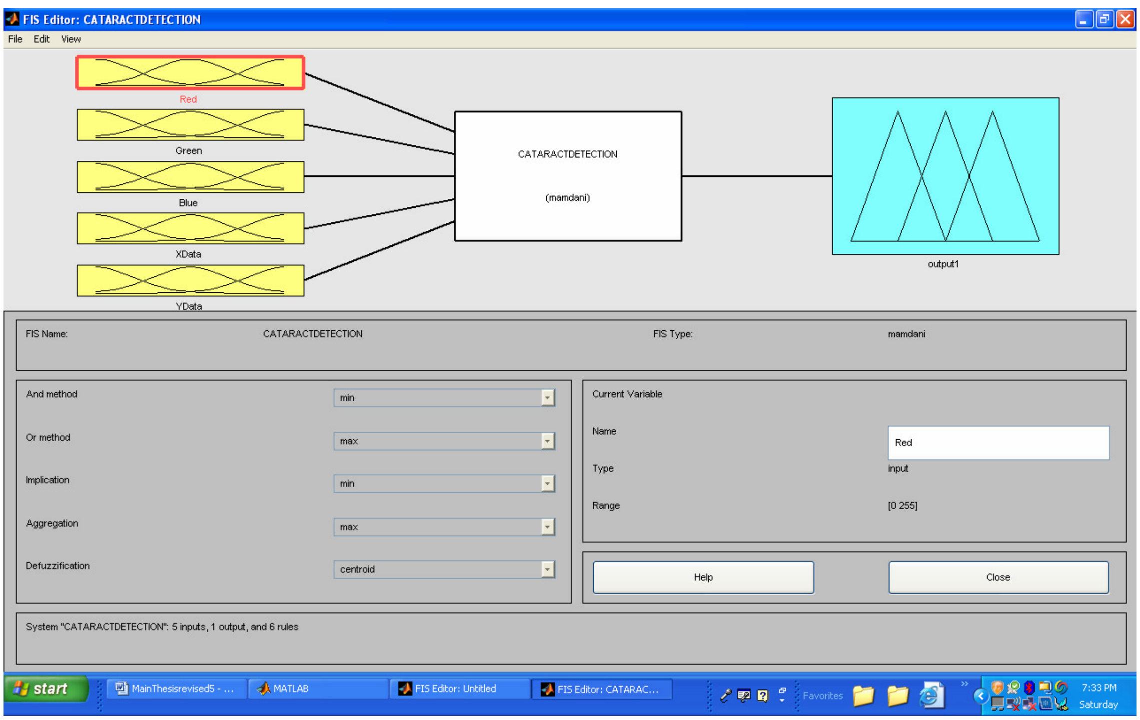
Screen 5: Red value from RGB file



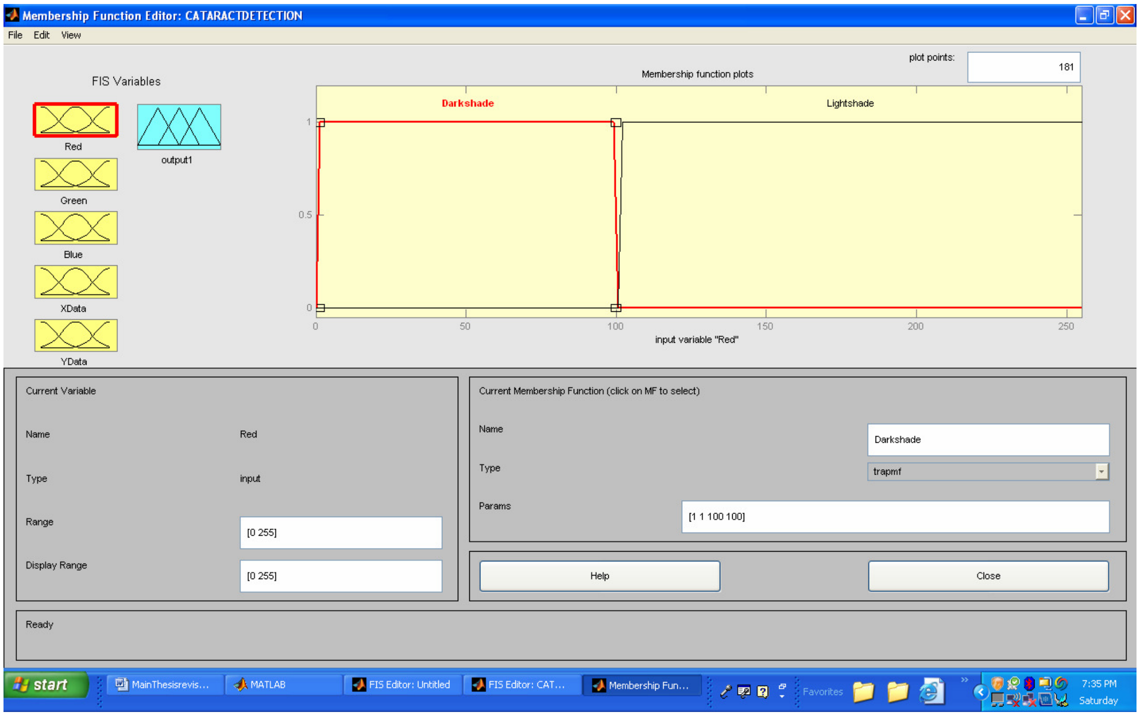
Screen 6: Green value from RGB file



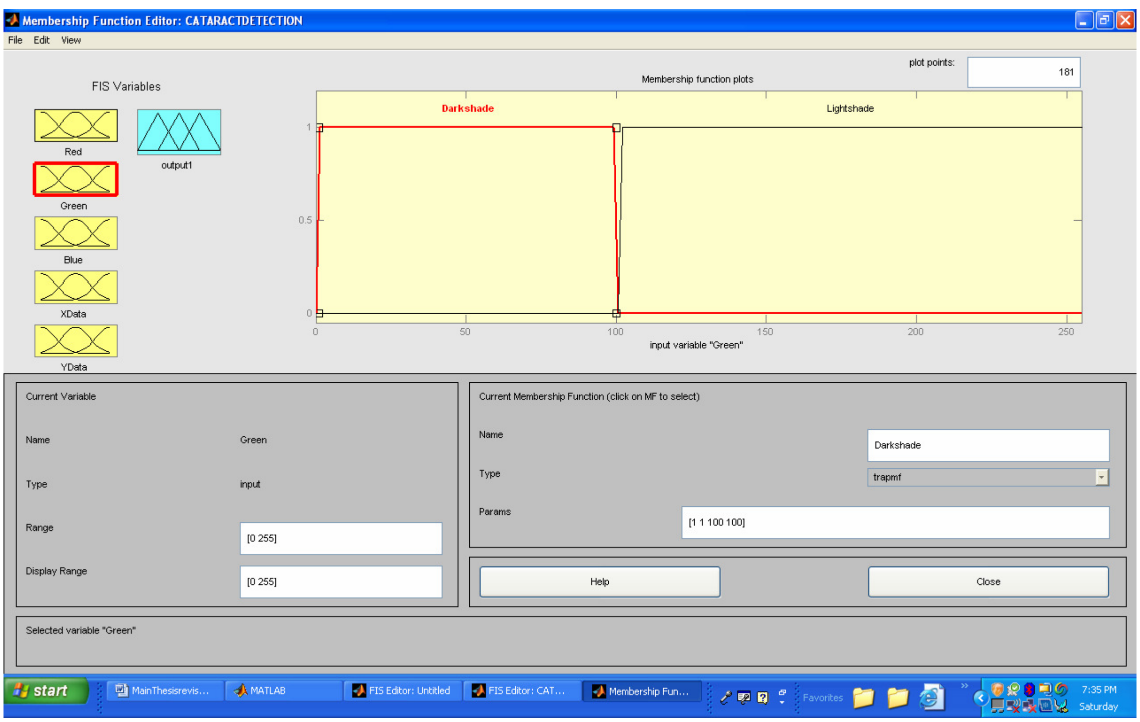
Screen 7: Blue value from RGB file



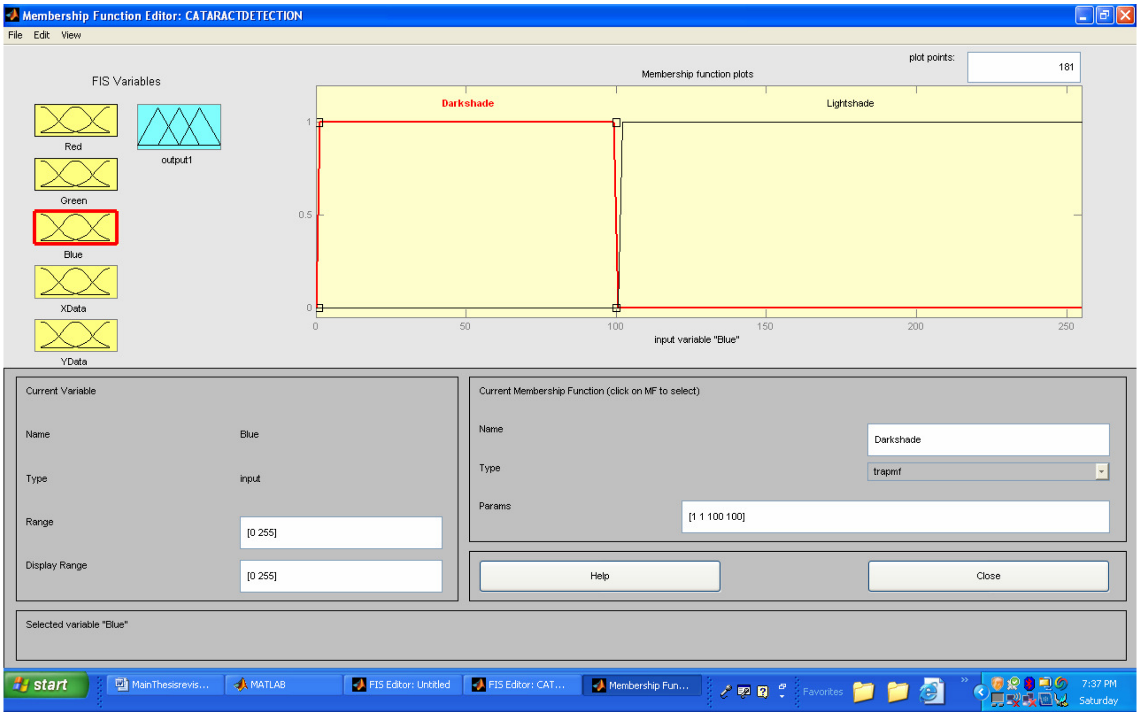
Screen 8: Fuzzy Inference System



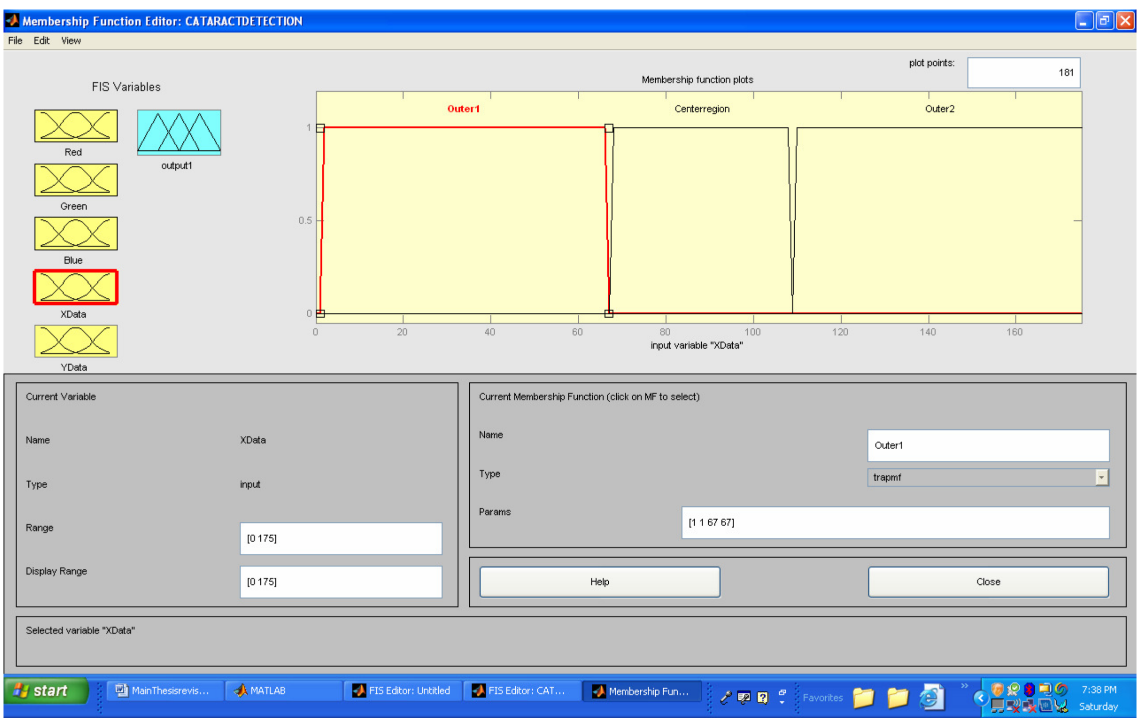
Screen 9: Membership function for input – red



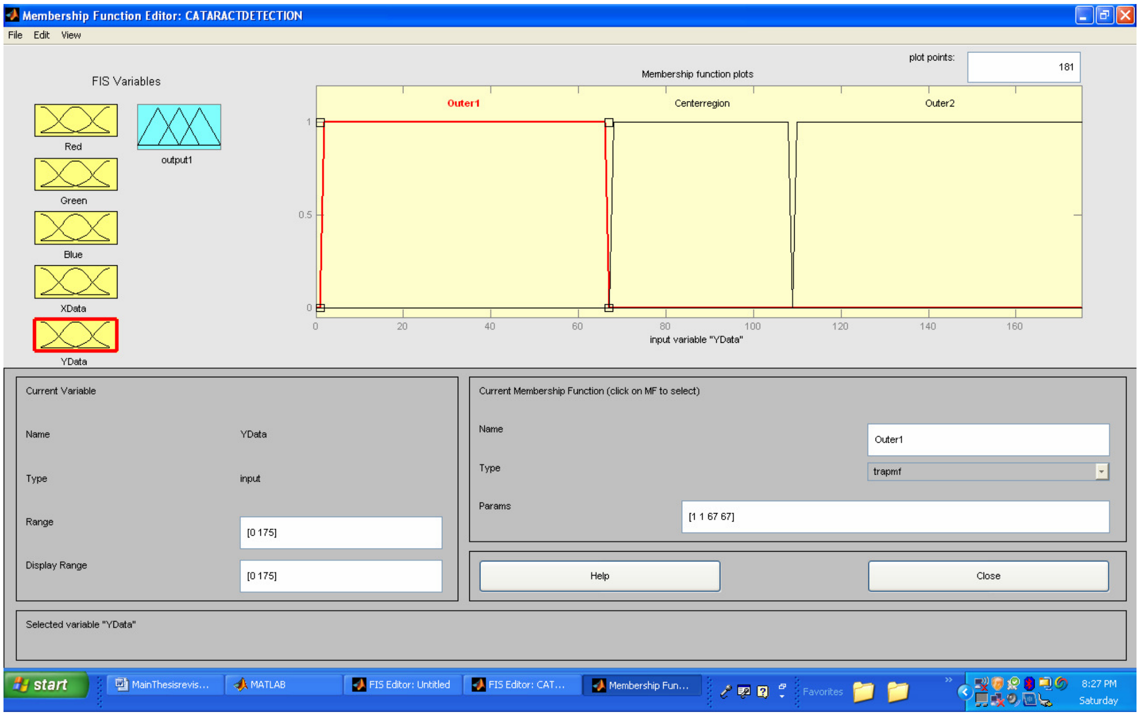
Screen 10: Membership function for input –green



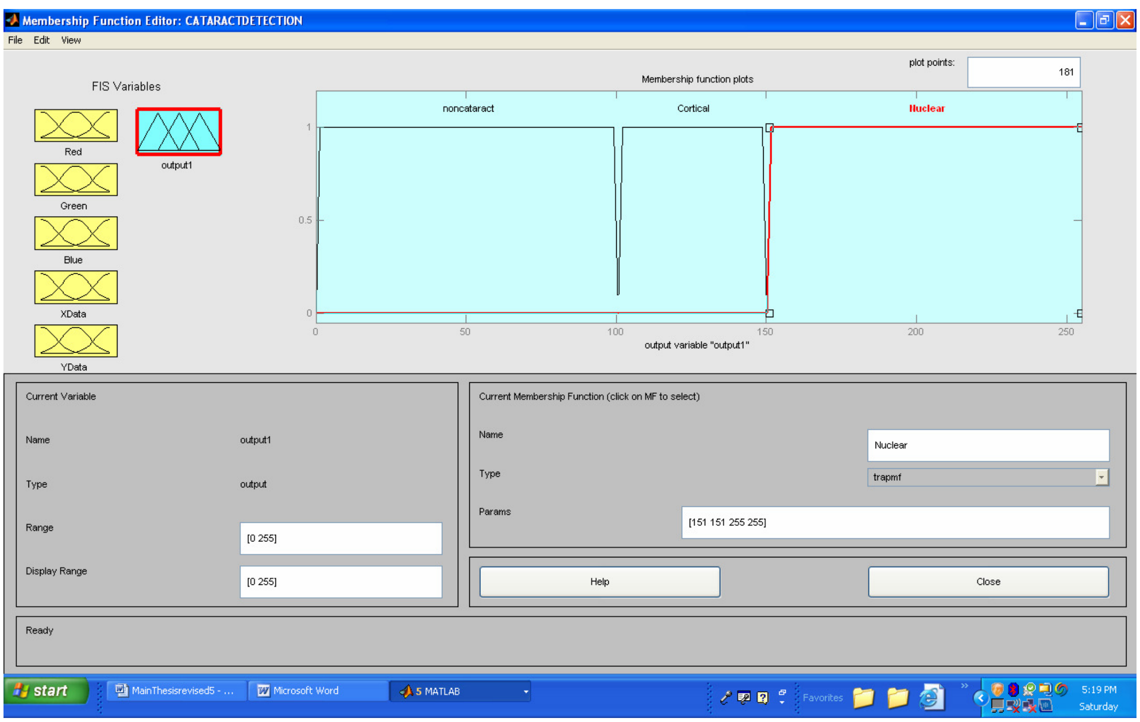
Screen 11: Membership function for input – Blue



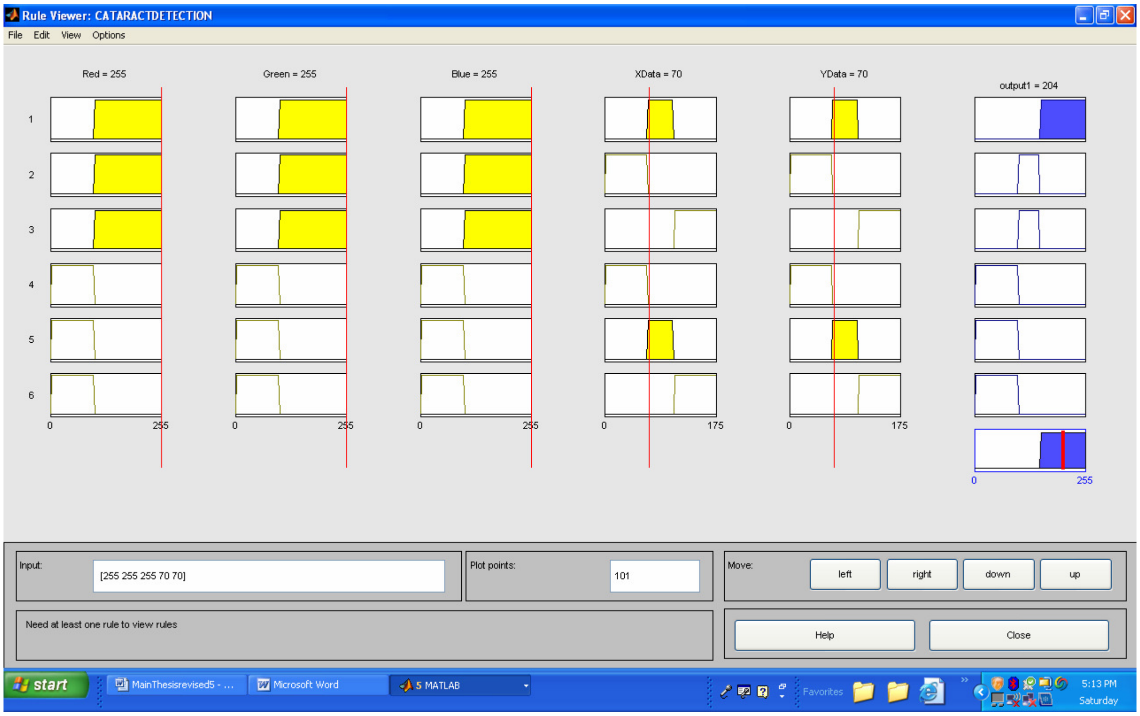
Screen 12: Membership function for Xdata



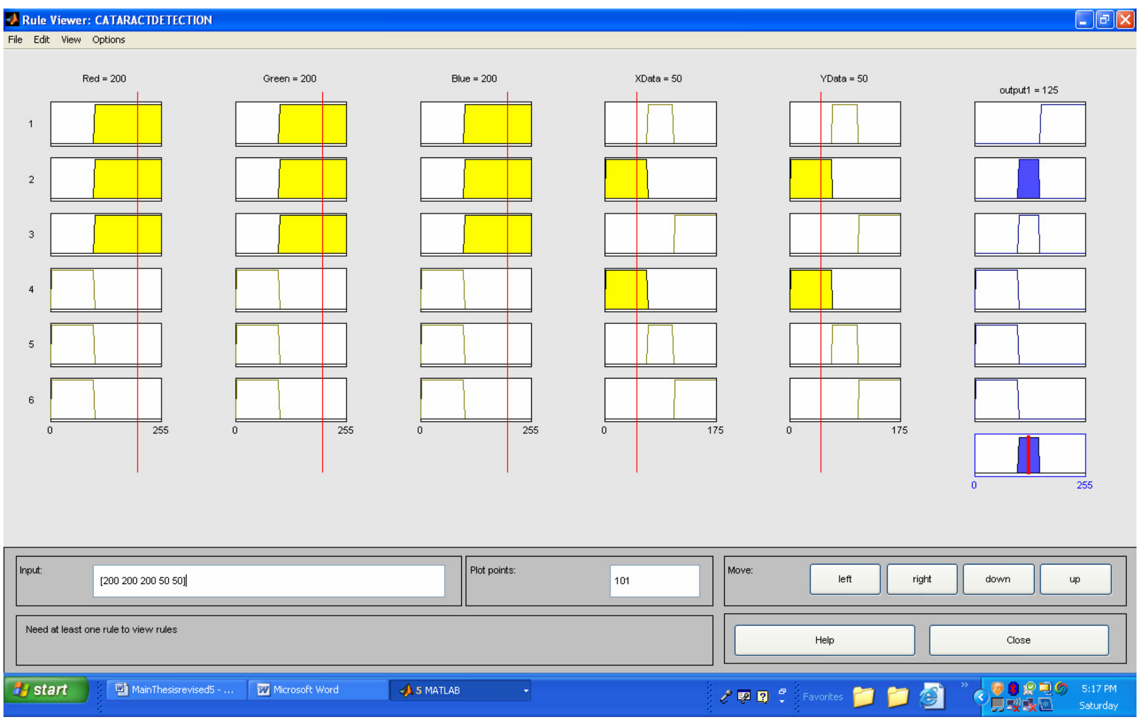
Screen 13: Membership functon for Ydata



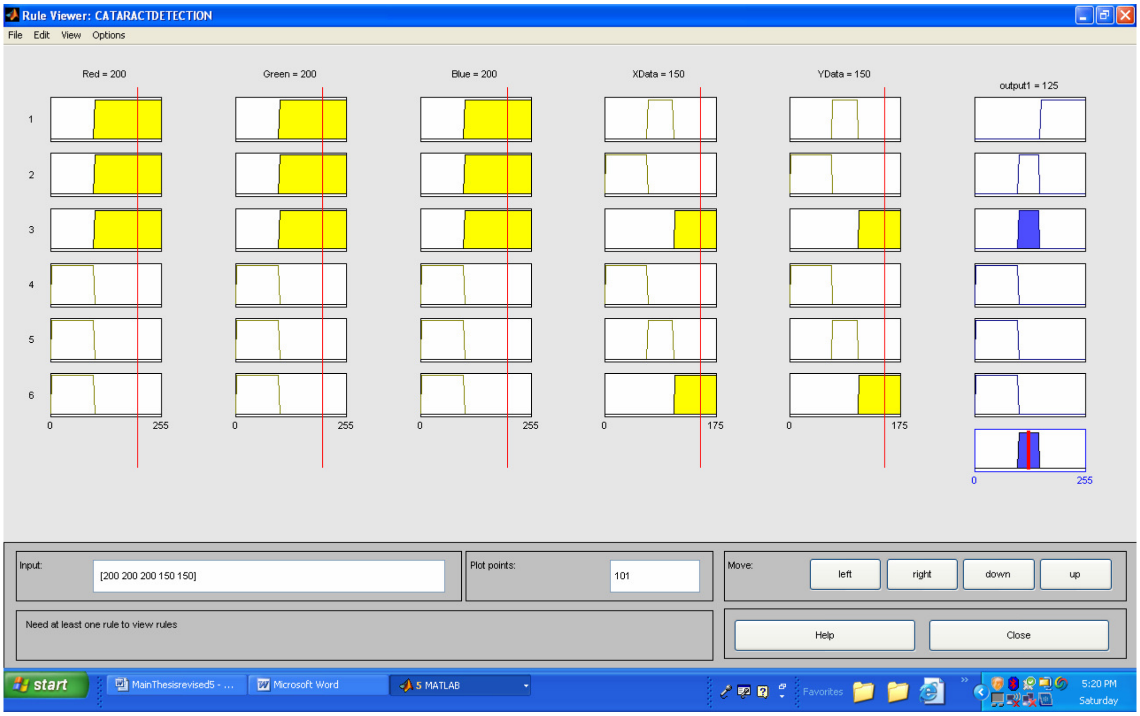
Screen 14: Membership function for Output



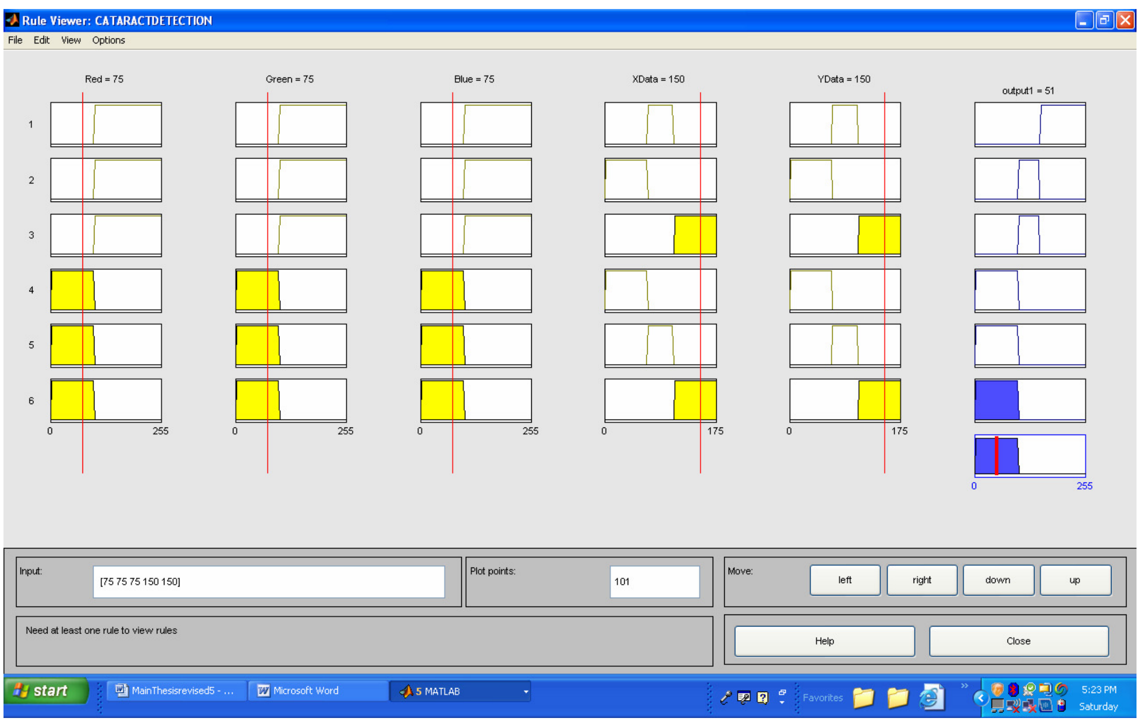
Screen 15: Rule Viewer Output = 204 (Nuclear)



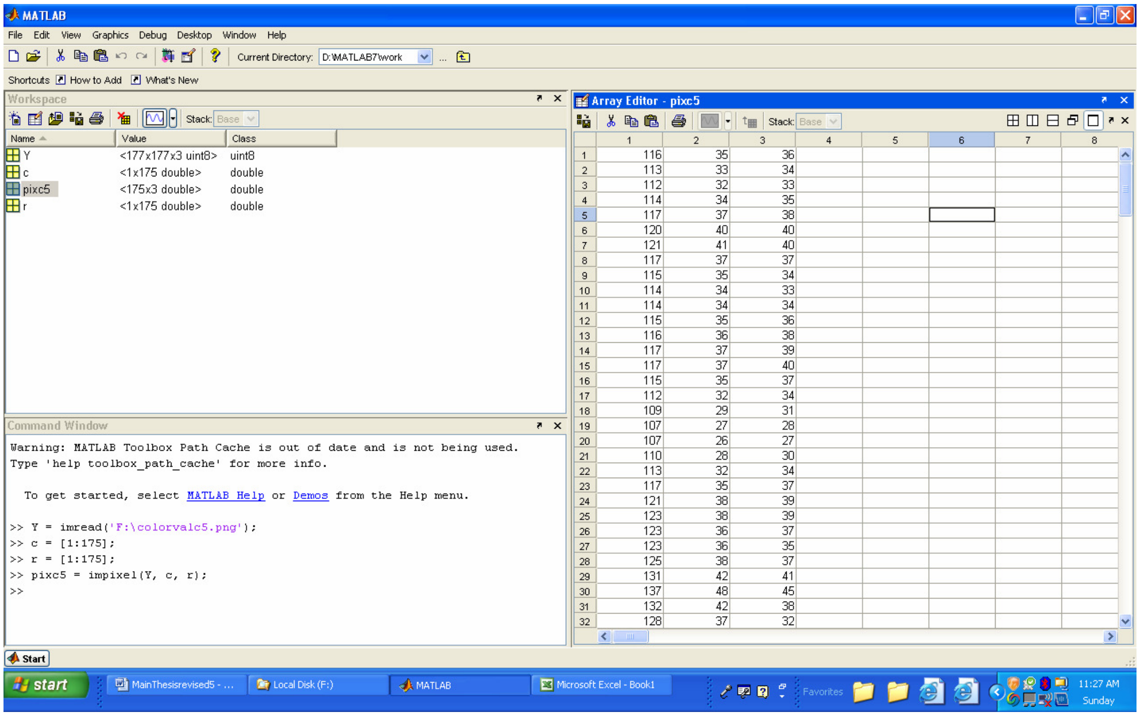
Screen 16: Rule Viewer Output = 125 (Cortical)



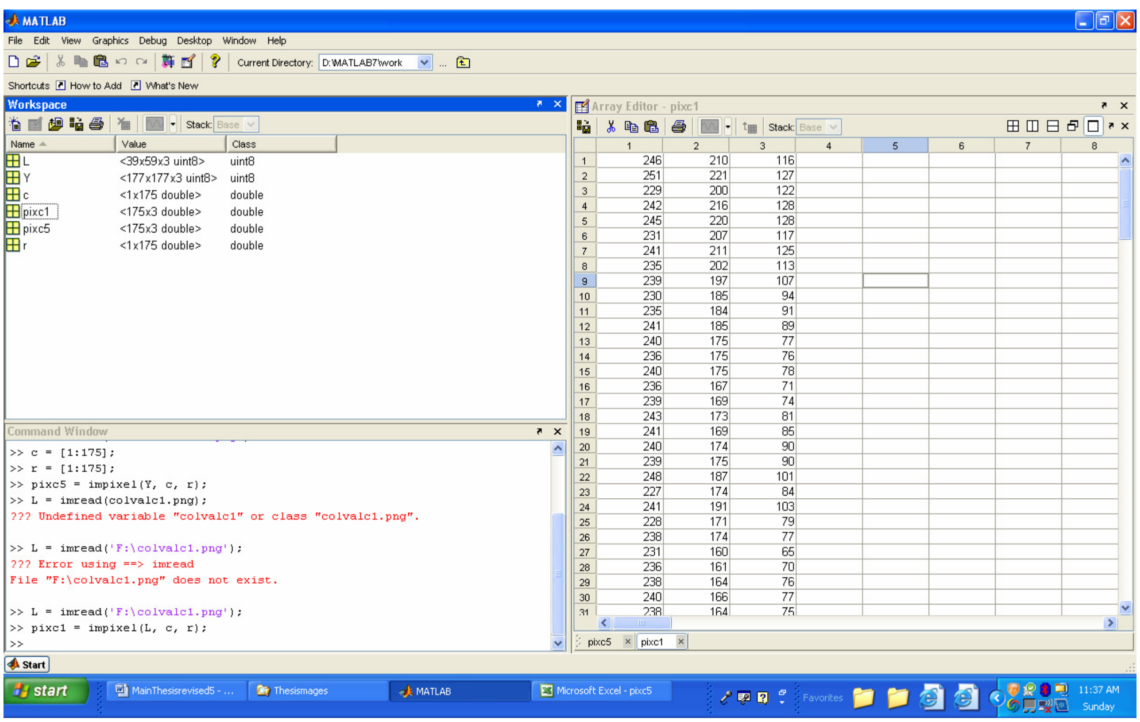
Screen 17: Rule Viewer Output = 125 (Cortical)



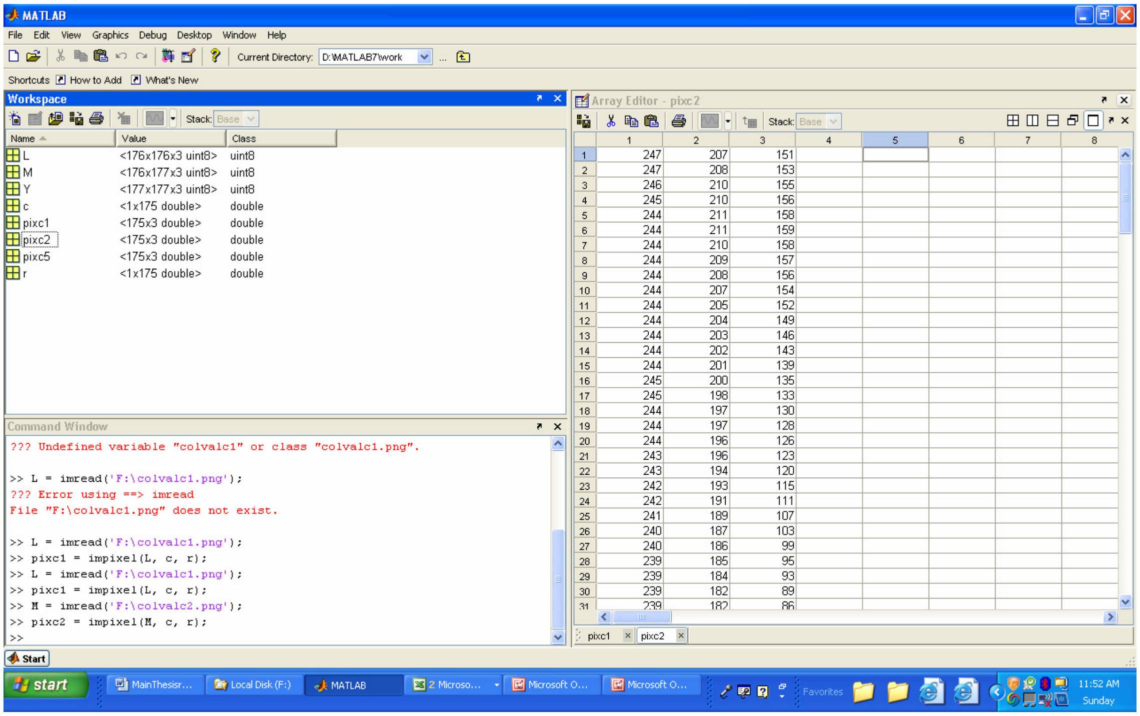
Screen 18: Rule Viewer Output = 51 (Noncataract)



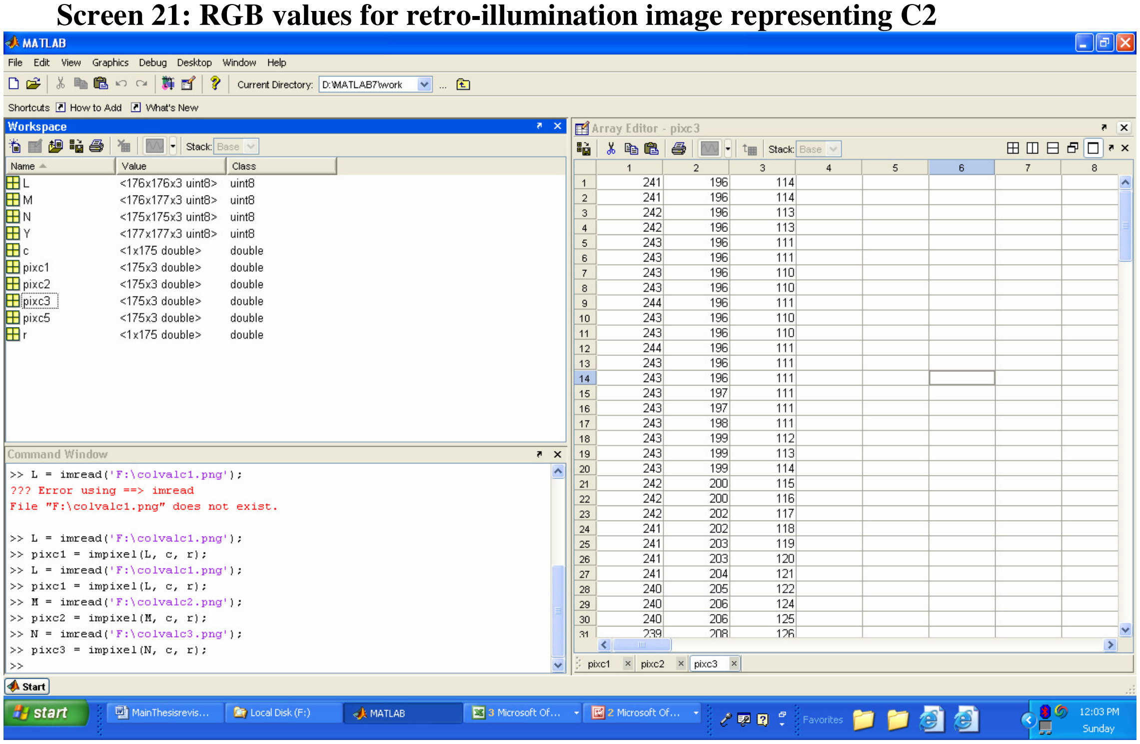
Screen 19: RGB values for a retro-illumination image representing C5



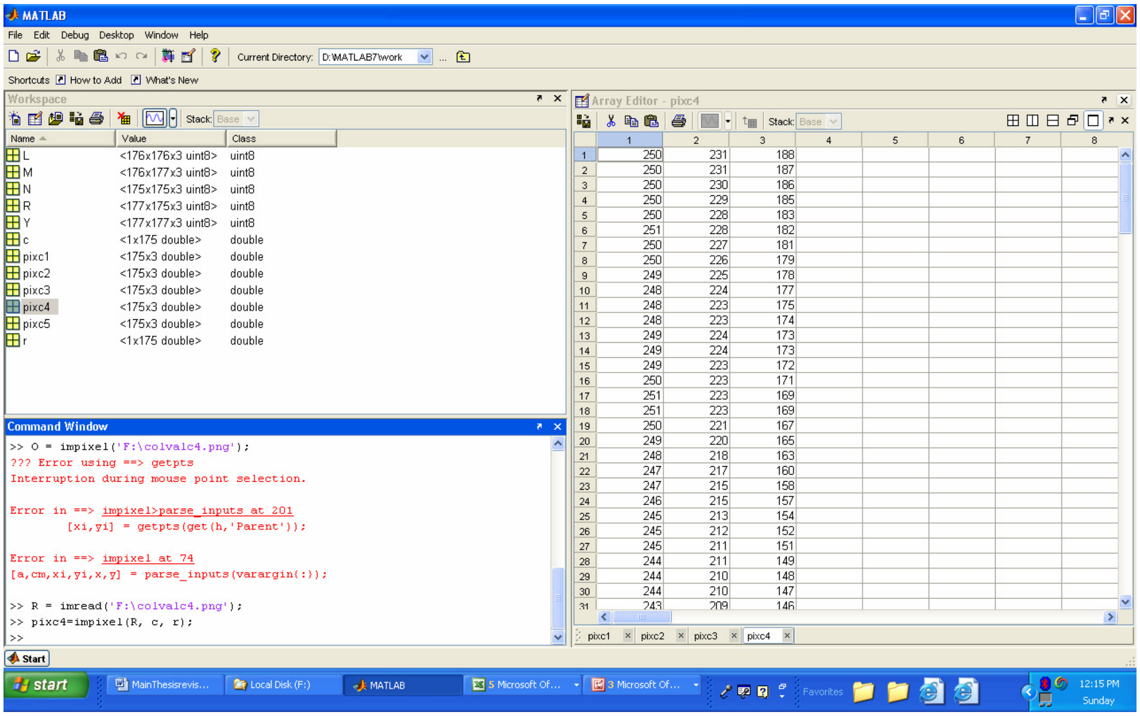
Screen 20: RGB values for a retro-illumination image representing C1



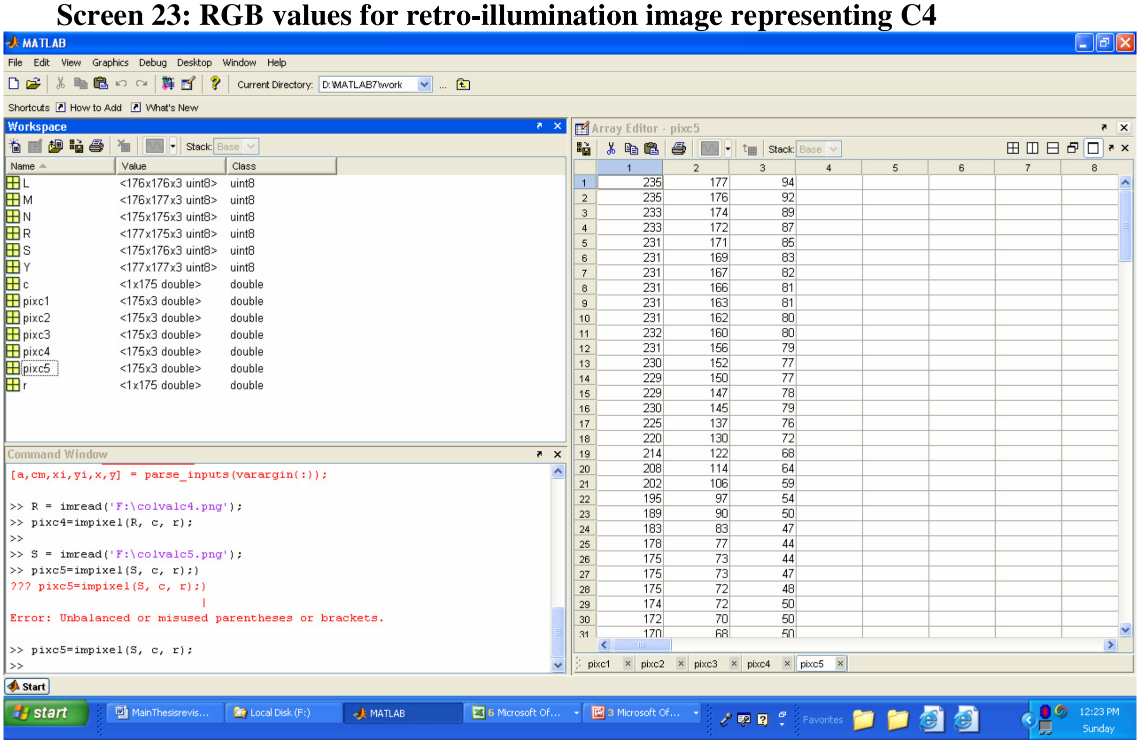
Screen 21: RGB values for retro-illumination image representing C2



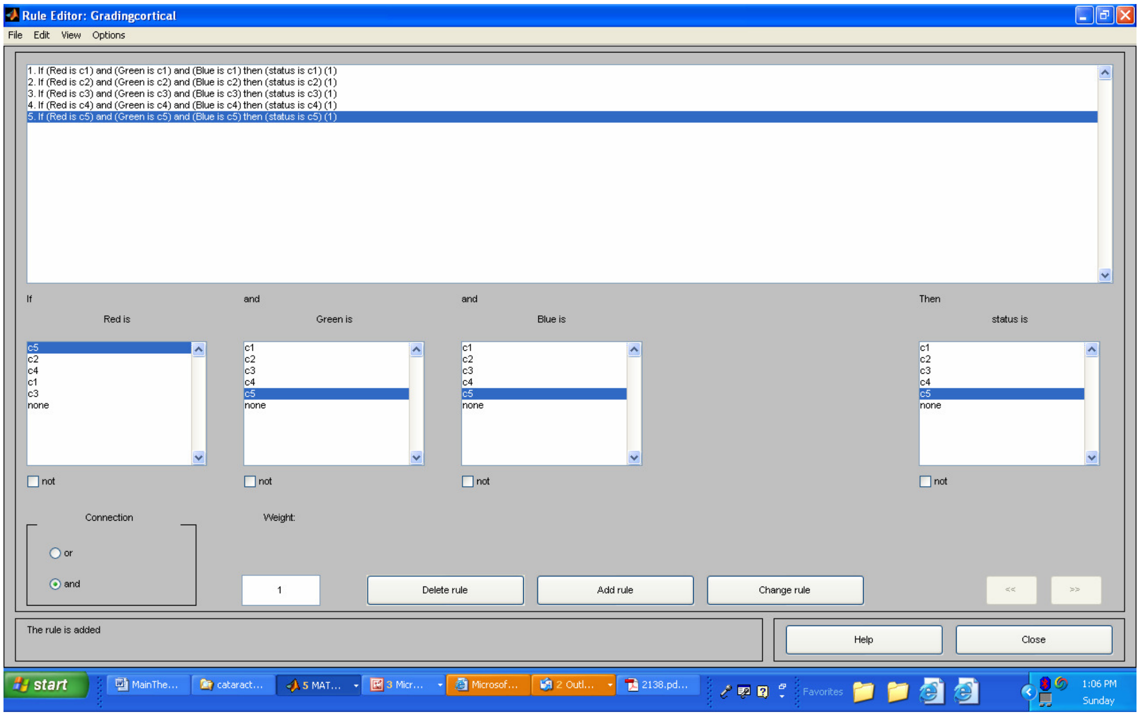
Screen 22: RGB values for retro-illumination image representing C3



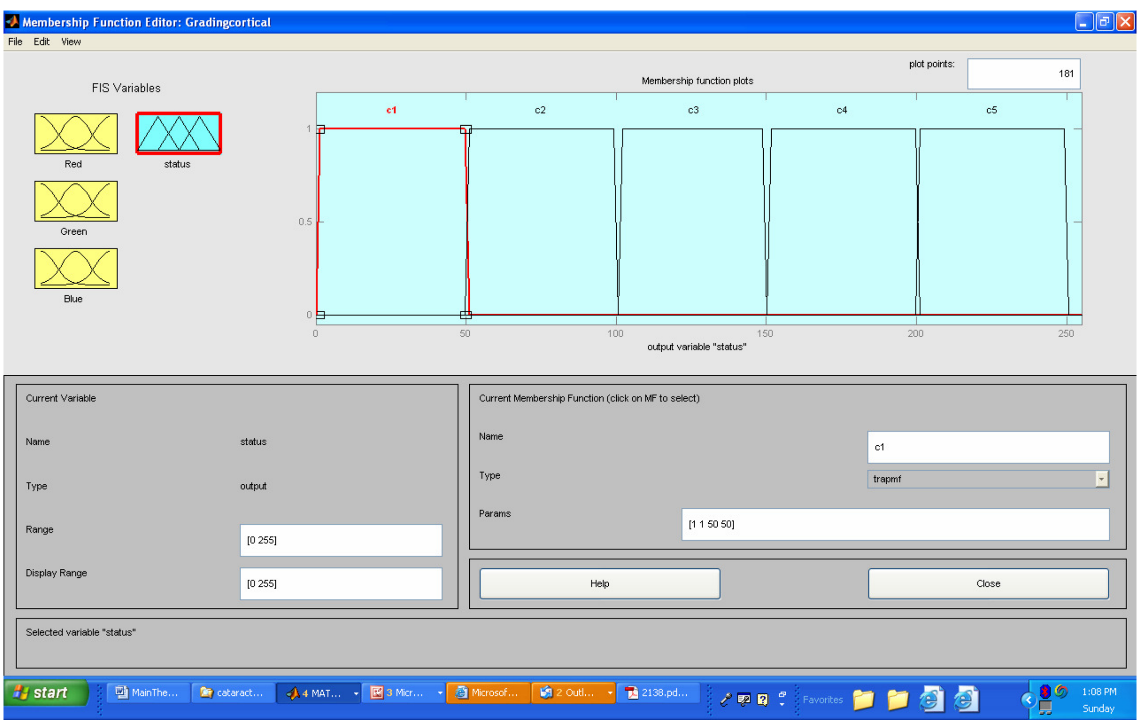
Screen 23: RGB values for retro-illumination image representing C4



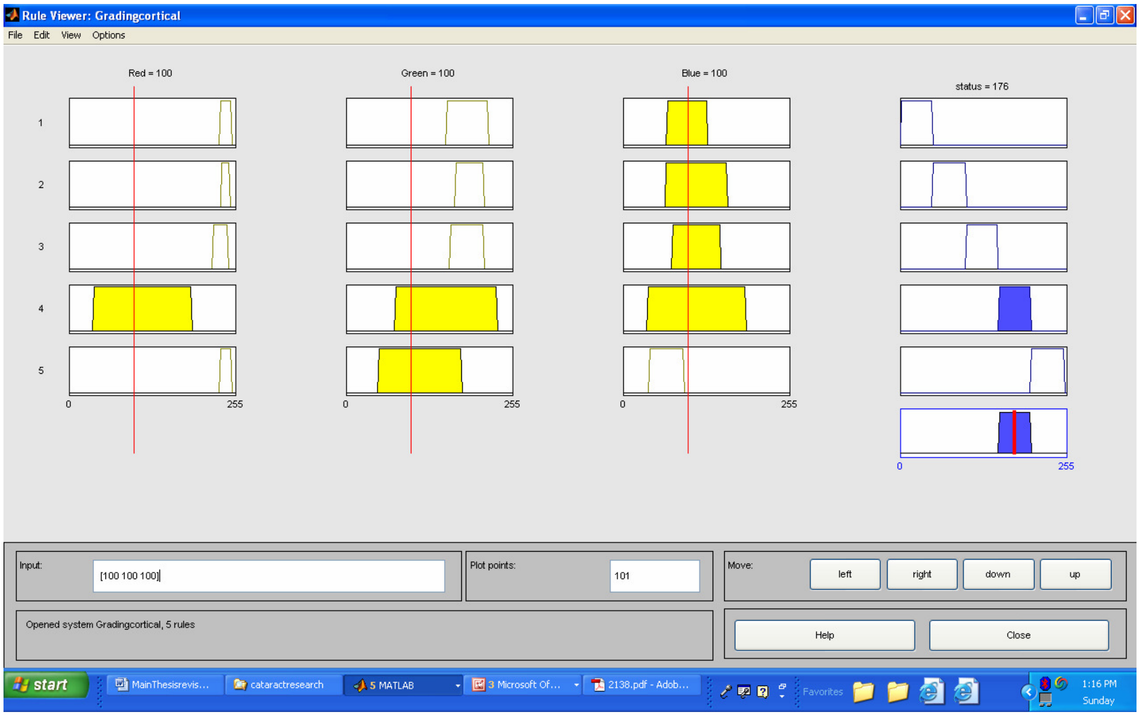
Screen 24: RGB values for retro-illumination image representing C5



Screen 25: Rule Formulation for Grading Cortical cataract



Screen 26: Membership function for output



Screen 27: Rule viewer for Grading Cortical cataract

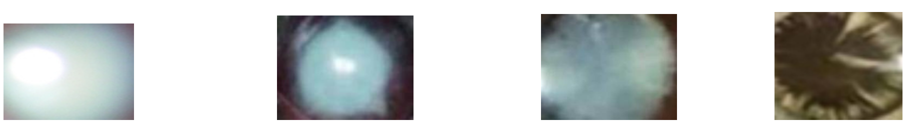
Appendix B - Platform Used

The following were the Hardware and Software requirements of the system developed in this Research work.

1) Operating System: Microsoft Windows XP
2) Development Environment: MATLAB 7.0 for FIS, Microsoft VB.NET for development of crude algorithm, Microsoft Picture Manager
3) Hardware:
   a) Processor: Intel Core 2 Duo processor
   b) RAM: Minimum 256 MB and upto 1 GB DDR2
   c) Hard Disk: Minimum 40 GB and upto 160 GB
   3.1) Slit – lamp model: TopCon SL6

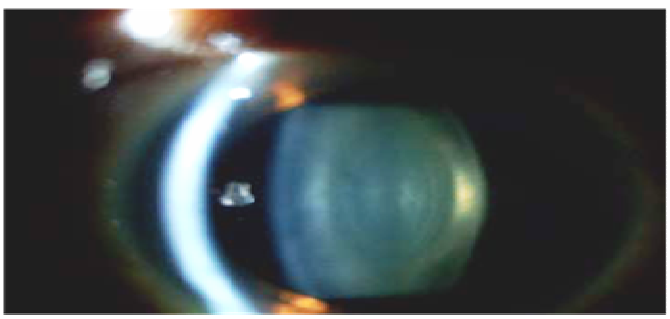
Appendix – C Photo Gallery

Some Cataract Images

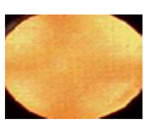


Some cropped cataract images

Some cropped normal eye images



Some retro-illumination images



Some cropped retro – illumination images

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