Analysis of Retinal OCT images for Fovea Localization and Macular Edema detection

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MS Computer Software Engineering

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Declaration

I hereby certify that I have developed this thesis titled as *"Analysis of Retinal OCT images for Fovea Localization and Macular Edema detection"* entirely on the basis of my personal efforts under the sincere guidance of my supervisor Dr. Muhammad Usman Akram. 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.

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Language Correctness Certificate

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

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Copyright Statement

Acknowledgements

Dedicated to my Exceptional Parents, my supervisor Dr. Muhammad Usman Akram, my elder brother Waqas and my dear friends Sadaf, Amna, Hana, Memona, Nida and Muntaha whose tremendous support and cooperation led me to this wonderful accomplishment.

Abstract

Macular edema is the blurring or loss of central vision which is caused as a result of Diabetic Retinopathy. According to WHO statement, there are 12.9 million people suffering from Diabetes in Pakistan which is almost 10% proportion of the whole population. The OCT imaging is a new technology which gives detailed view of retinal layers. Analysis of OCT images helps in identification of multiple diseases. Fovea is the central part of retina which is responsible for central vision. The aim of this research is the successful localization of fovea which can be further used for the detection of multiple diseases. First the extraction of ILM layer has been done by using Active Contour based Segmentation and Curve Fitting Techniques. A new technique is proposed in this research for the successful localization of fovea in retinal ILM layer by using distance based method. The detection of Macular edema has been done on the basis of analysis of fovea region. The system is evaluated using a local dataset of OCT images which is gathered with the help of Armed Forces institute of Ophthalmology. The dataset consists of 550 images and the developed system gives an accuracy of 92% for Fovea Localization and 84% for Edema detection.

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CHAPTER 1: INTRODUCTION

Optical Coherence Tomography (OCT) is a modern type of imaging technique related to Optical Modality. This imaging was first determined in 1991 [1]. It was first performed *in vitro* (study on cells outside its normal context) of human eye for the purpose of examples of OCT imaging in a weakly scattered, transparent media and high scattered, non-transparent media. The very first *in vivo* (study of cells within a living) tomograms of retinal Macula and Optic Disk were taken in 1993 [2,3]. OCT imaging technique initially was applied for cross-sectional imaging of eye but now it has largest clinical applications in the field of Ophthalmology. This technology was introduced and shifted to industry and commercially introduced for diagnosis of Ophthalmological diseases in 1996. Figure1.1 shows the evolution of OCT with time.

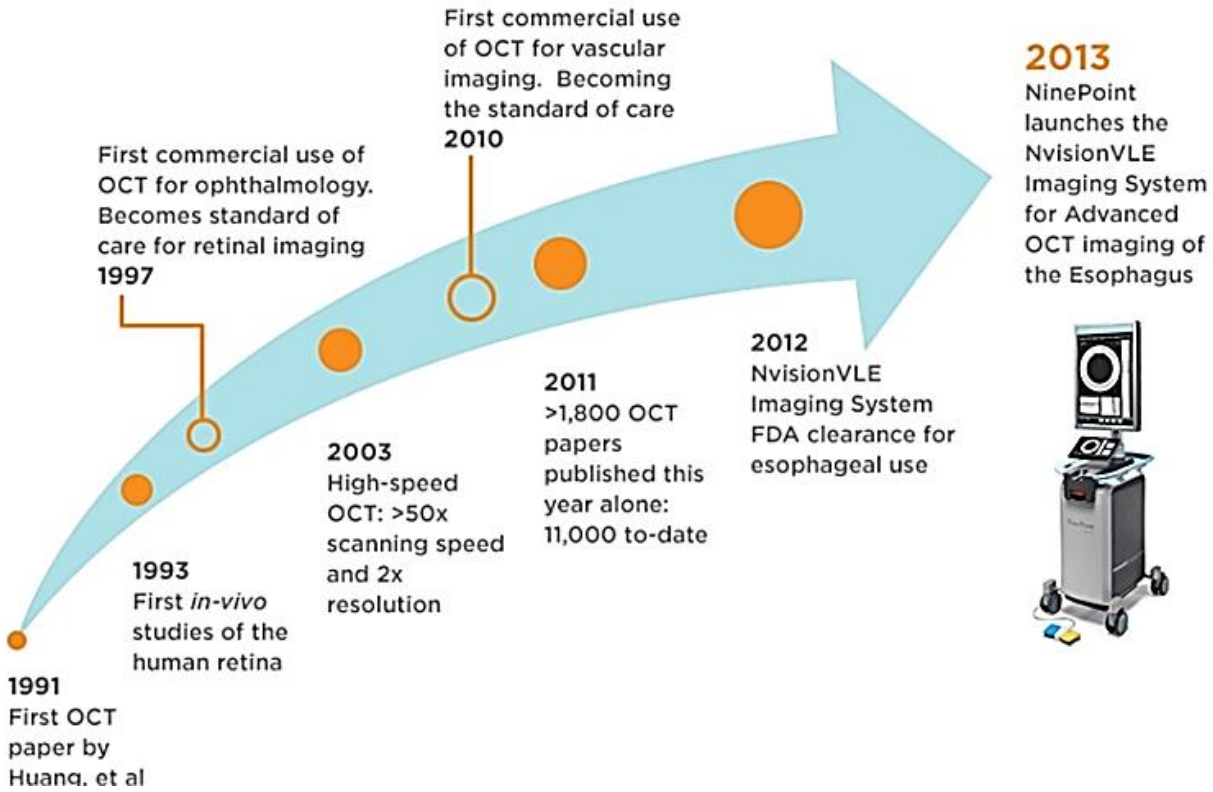

Figure 1.1: Evolution of Optical Coherence Tomography[38]

OCT has made numerous developments in many different fields like real time, high speed OCT images has been achieved with the rate of acquisition of many frames per second [8,9,10]. Similarly ultra-high and high resolution OCT images have been acquired with the help of laser light source along with high axial resolution of 1µm has been acquired [11-13]. OCT imaging at cellular level by developmental biology-specimen has recently been demonstrated [14]. OCT

interfacing with endoscopes, laparoscopes and catheter has also been practiced for the purpose of imaging of internal body [15, 16].

OCT is very much similar to Ultrasound imaging; the difference lies is that OCT uses light while ultrasound uses sound waves of ultrasound imaging. Ultrasound imaging having High-frequency is able to provide the depth of images of a very few millimeters while OCT imaging can give the image resolutions from 1-15 μm. Also the transverse-resolution of ultrasound images is estimated by the ability of sound waves to focus and generally the sound waves are more difficult than light waves to focus. Hence the transverse-resolution of ultrasound imaging is lower than that of OCT imaging.

There are three general scenarios in which OCT imaging applications helps a lot: 1) where due to sampling errors, conventional biopsy is giving such high false negative rate that is totally unacceptable, 2) where excisional conventional biopsy is impossible to practice or is hazardous, 3) where interventional surgical procedures related guidance is required.

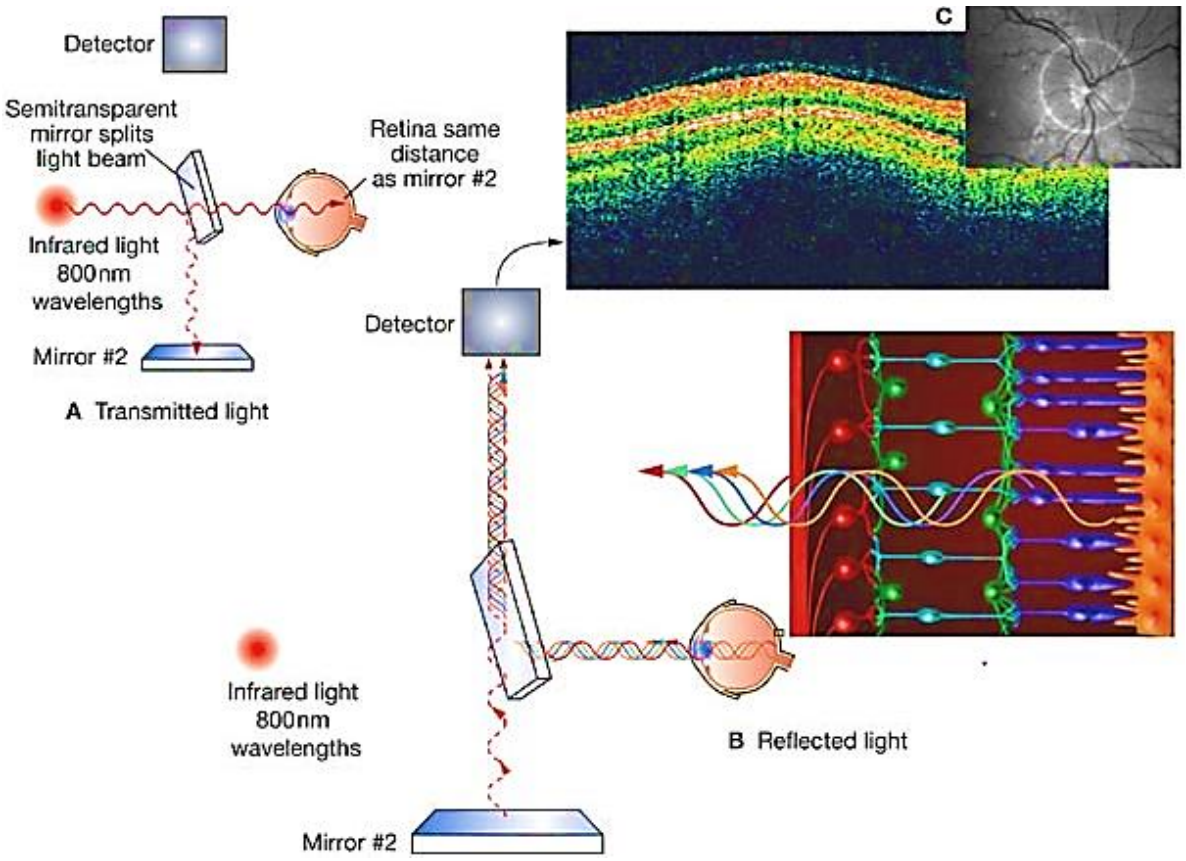

Figure 1.2: OCT Image Capturing Process[39]

OCT provides high-resolution and cross-section view of images which are of internal-structure of materials and biological system, through the measurement of back scattered light. OCT

images are two dimensional or three dimensional images representing optical back reflecting through the tissues in cross sectional plane. Figure1.2 demonstrates the process of capturing an OCT image.

According to Figure1.2:(A) Infrared light of low coherence transmits into the human eye using Interferometer. This transmitted light transmits through the pupil of eye and goes through the 9 transparent layers of human retina. Infrared light then backscatters through the pupil in Figure1.2:(B). After that the detectors does analyze the returning light interference compared with the light following the reference path (mirror #2).

Mathematically an algorithm does use this information to form a gray scale or a false color image representing the retina (right upper portion of Figure1). Figure1.2:(C) is a fundus image with properly centered optical disk and surrounded the target OCT image circumference marker. OCT can provide images of 1-15 μm resolution which is of 1-2 orders high magnitude than ultrasound. An OCT image shows the detailed view of multiple retinal layers clearly. Figure1.3 is an OCT image with the detailed retinal layers of a Healthy human eye. Multiple diseases can be identified through the analysis of changes occurring in retinal layers.

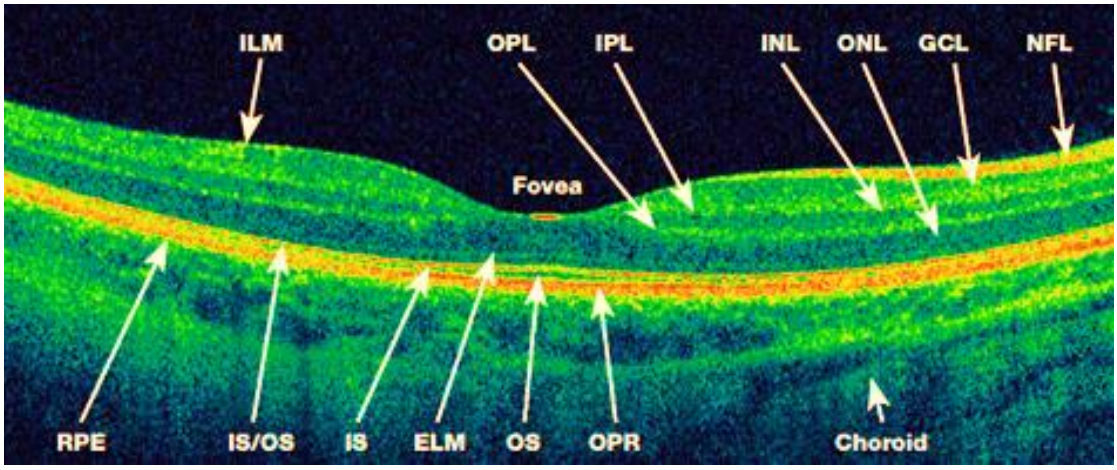

Figure 1.1: OCT Image of a Healthy Human Eye[40]

These unique features of this technology make it applicable and useful in many areas of medical research and applications. OCT not only enables non-invasive imaging of interior of eye but also provides morphological features of human eye which also includes optic disk and fovea [4-7].

Many different clinical studies and research has been done in this field in past few years and there is a lot more to do in this field.

Fovea which is sometimes known as Fovea Centrails is located at the center of the macula. It is the region which is of acute-vision and this is the region responsible for the healthy vision of an

individual. Fovea is the central part of retina which is represented by a dip in retinal part of eye. It is the place where mostly Cone cells are present [17]. Figure1.4(left) is a fundus image of a retina showing fovea and Figure1.4(right) is an OCT image of healthy retina having fovea.

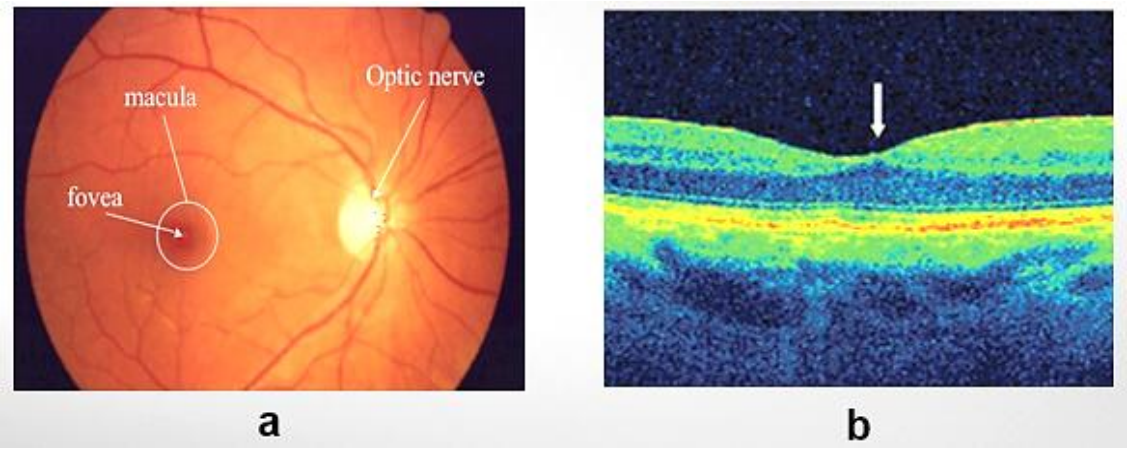

Figure 1.2: (a) Fundus Image Fovea (b) OCT Image Fovea[41]

AMD diseases affect the central vision (fovea) of a human eye most. Mostly daily routine activities like reading involves very much use of foveal muscles which in case of any disorder can very badly affect daily routine activities of an individual. There are no blood vessels in fovea unlike peripheral retinal part of eye. Instead this part contains much high concentration of cones which helps in recognizing colors. It is also very important to localize fovea in a fundus image as many different techniques use it in the diagnosis of multiple diseases.

Macula is a very small part of retina which is at the central area of retina. Rays of light gets focused on the retina from where they are transmitted to the brain which interprets these rays as an image. Macula is the region which is responsible for the pinpoint-vision allowing a person to be able to sew or read. This pinpoint vision capability of a person can be disturbed due do damage in macular region.

Macular Edema is the disease in which the macular part of eye gets damaged causing central vision blurring and in severe case the loss of vision. Macular edema is caused due to the leakage of fluids out of blood vessels in retina. The fluids leakage out of blood vessels causes swelling and thickening of Macula and as a result loss of detailed vision.

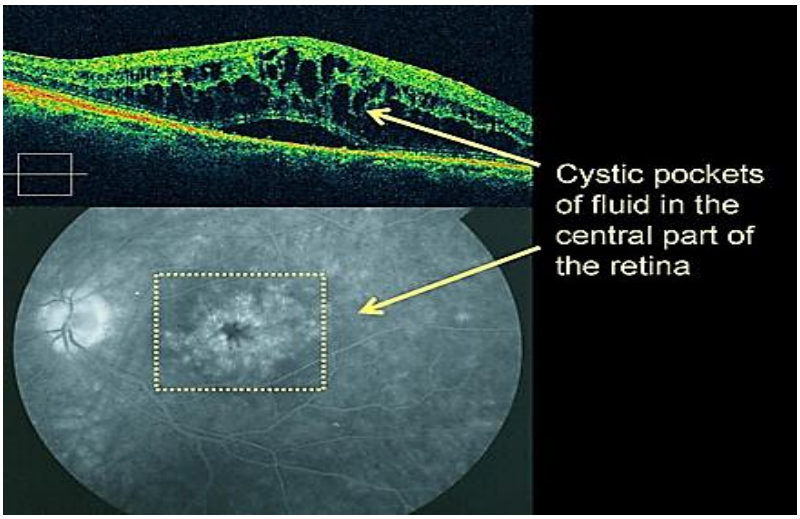

Figure 1.3: Macular Edema Localization in OCT and Fundus Image[42]

Figure1.5 shows the macular edema pointed out in an OCT image and a fundus image. Since Macular Edema causes prominent changes in fovea region in OCT that's why Macular Edema can be identified through the localization of fovea region and after that analysis of fovea region in an OCT image. On the basis of changes occurring in fovea region, Macular Edema can be easily identified.

The aim of this research is the detection of Macular Edema through the analysis of OCT images of human macula and the analysis of OCT images for the localization of Fovea point in an OCT image which can be very helpful for the identification of multiple diseases. Also the aim of this research is to develop a complete Fovea localization and Edema detection system using a system development life cycle model (SDLC).

Development of a software system using a suitable life cycle model is of great importance. SDLC is the development of a system or an application following the process of planning, creating, testing and deploying for the success of system under development. There are multiple SDLC models like waterfall model, iterative model and incremental model etc. and to ensure the success of system developed, the perfect model to follow is decided on the basis of requirements of the system under development. Figure1.6 shows different phases of a Life Cycle Model.

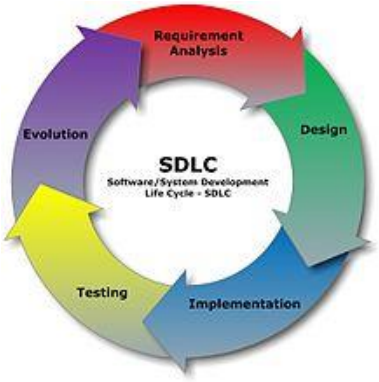

Figure 1.4: System Development Life Cycle Phases[43]

1.1 Motivation

AMD diseases affect the central vision (fovea) of a human eye most. Mostly daily routine activities like reading involves very much use of foveal muscles which in case of any disorder can very badly affect daily routine activities of an individual. Main motivation of this research is the localization of fovea region for the analysis of changes occurring in that region and in turn the identification of such diseases. Since Diabetes is Worldwide Problem and there are almost 135 million people having diabetes worldwide. According to WHO statement data in 2011 there are about 12.9 million people having diabetes in Pakistan which is almost 10% proportion of the whole population and Macular Edema comes as a result of Diabetic retinopathy which causes the loss of central vision of human eye. A person having Diabetic Retinopathy is most likely to have macular edema too. Also not much work is being done in the field of Retinal OCT imaging in Pakistan as this is a new field and a little research work is already available in this field. Also this project has been funded by ICT R&D for the advancements in the field of ophthalmology at a national level. Armed Forces Institute of Technology has also offered its kind support and help in diagnosis of multiple retinal diseases. Another motivation of this work is the less usage of SDLC models in the development of Biomedical Applications. It is very rare that a system development model is used to develop some biomedical application. Hence the aim is to develop a complete biomedical system using a SDLC model.

1.2 Objective and scope of Thesis

The main objective is the localization of Fovea point in an OCT image with maximum accuracy. Another objective is the detection of Macular Edema through the analysis of changes occurring

in the macular region of an OCT image. Finally the step by step development of Edema Detecting system by following Iterative Prototyping system development life cycle model which includes the requirements gathering, analysis of requirements to get system specifications, system designing, development, testing and maintenance of system developed. Some other objectives of this research are:

- To motivate other researchers to make contributions in this field as there is not much work done in OCT imaging.
- To provide an initial Edema detection system through OCT analysis which can be further modified and improved by other researchers.
- To link software engineering concepts with the development of biomedical systems which is quite necessary to increase the system accuracy.

1.3 Challenges

AMD related many diseases can be identified through the localization of Fovea and Optic Disk and there is much work done in this regard for fundus image and there are many different algorithms which can localize fovea and optic disk in fundus images with very high accuracy. But there is not much work done for the localization of fovea in OCT images. Only a few algorithms have been proposed for fovea localization in OCT images. Some of the key challenges are:

1.3.1 Related Work Already Done

There is no work done already for localization of fovea in OCT images so the related work done is a big challenge for the comparison purpose of Localization techniques.

1.3.2 Data Set Availability

Since OCT is quite a new field and there is not much equipment available easily hence there is not much data available categorically for research purposes. That's why collection of data set is a big challenge to carry out the research. Also if some data is available then mostly there is no permission to use that data publically. Armed Forces Institute of Technology has offered its kind support and help in diagnosis of multiple retinal diseases and has provided the OCT imaging data set for the research purpose.

1.3.3 Following up SDLC Model Phases

It is a challenging task to keep track of different phases of SDLC and develop the system step by step. Documentation of each phase is also another challenging task.

1.4 Structure of Thesis Report

The report is organized as follows:

- Chapter2 contains the detailed overview of Macular Edema. It includes the causes and effects of Macular Edema in very much detail for an understanding of Edema. This chapter also contains a detailed explanation of System Development Life Cycle phases and their different types.
- Chapter3 is about the related work already done regarding fovea localization and Edema detection.
- Chapter4 is about the technique and algorithm used for the Fovea localization and Macular Edema detection. It explains all the details of methodology used.
- Chapter5 contains the details about the data set used for this research. This chapter also includes results achieved.
- Chapter6 is about the SDLC model application to the development of whole system. It explains step by step development of this system using Iterative Prototyping SDLC model.
- Chapter7 includes the Future work and Conclusion.

CHAPTER 2: Macular Edema and SDLC

2.1 Macular Edema

2.1.1 Background

Before the invention of Ophthalmoscope, the existence of Macular Edema or the fluid accumulation in general was mostly unknown. Jaeger in 1856 published one of the first reports on diabetic-maculopathy. The observations of Jaeger were confirmed by Nettleship almost twenty years later. Also Appolinaire in 1875 described lipid and fluid accumulation in macula which led to the concept of glucose-induced amblyopia. Tartuferi in 1882 proposed first hypotheses related to accumulation of fluid in posterior-pole. According to that hypotheses the edema was caused due to swelling in photoreceptor-sheaths. The Frenach-man Neul in 1896 proposed the term 'oedème maculaire' which was observed by him in a retinitis-pigmentosa patient. Not until the ending of world war-I an Ophthalmologist Alfred noticed macular edema in many other ocular conditions. Quarter century later a German term was proposed by Bangerter named 'Zystoides Makulaödem'. Then Hruby in 1950 was the person who first drew attention towards the macular edema development after cataract-extraction. Thirteen years later cystic fluid accumulation phenomenon in macula was further improved by Norton and Gass ith the help of fluorescein angiography.This is how the concept of Macular Edema emerged with time.

2.1.2 Introduction

Macular Edema is observed when due to protein deposits collection under the macula of eye, swelling and thickening results in at the Macula. This thickening of Macula causes the central vision blurring and in severe cases the loss of central vision. Figure2.1 shows the effects of Macular Edema on the vision on normal eye vision.

There are two types of Macular Edema:

1) Cystoid Macular Edema (CME)
2) Diabetic Macular Edema (DME)

Figure 2.1: Effects of Macular Edema on Vision[44]

2.1.2.1 Cystoid Macular Edema

It is a painless-disorder which affects the central vision. It is caused due to accumulation of fluids in the outer-plexiform layer. Its symptoms include reduced central vision and blurring. Also it does not affect side vision. CME normally occurs after cataract surgery.

2.1.2.2 Diabetic Macular Edema

It is mainly caused due to leakage of macular capillaries. All Patients having diabetes are much likely to have this disease.

2.1.3 Macular Edema Detection

Since OCT provides cross sectional and high resolution image of retina along with various pathological features of macula which enables physicians to quantitatively measure the thickness and swelling in the macula for the identification and treatment of disease. This measurement of Macular thickness is essential for the identification of abnormal fluid accumulation in the neurosensory part of retina which most of the time leads towards Macular Edema. Once the disease has been identified then it is also necessary to keep the track of macular thickness for the record of its propagation and treatment purpose. Figure9 shows the OCT images of a normal and diseases macula. Figure2.2 (top) is an OCT image of a macula diseased with Macular Edema and Figure2.2 (bottom) is an OCT image of a healthy macula.

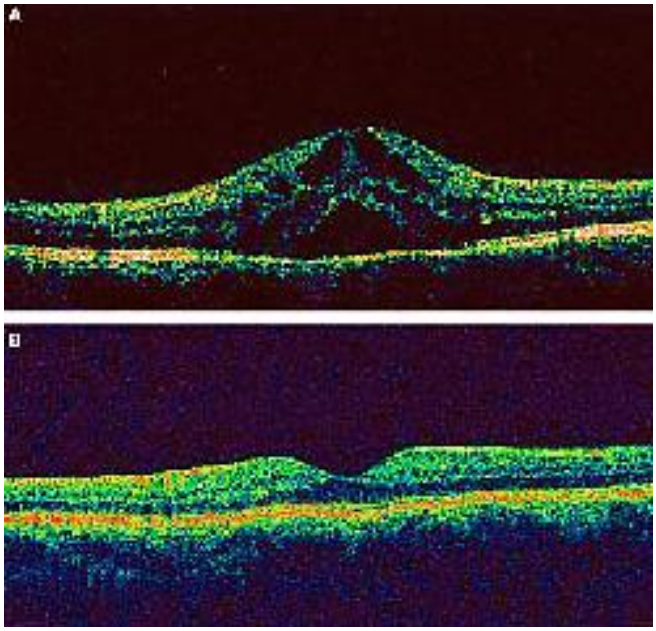

Figure 2.2: OCT Image of Diseased and Normal Macula

Since Macular Edema is caused mainly due to leakage of blood vessels of retina or some damage to retina and as a result leaking fluid starts to accumulate in the Macular part of retina. In an OCT image Macular Edema is identified by identification of effects of accumulated fluids in Macula by Ophthalmologists. This fluid accumulation causes formation of Cystic pockets in the Macula and Swelling in the Fovea region. Hence the identification of Macular Edema in an OCT image is based upon the identification of cysts/holes and swelling in macula. In this research the identification of Edema is done on the basis of identification of swelling in the Fovea region.

2.2 System Development Life Cycle (SDLC)

2.2.1 Background

A Systems Development Life Cycle (SDLC) is a methodology which is used to represent the process of development of a system and the system is developed in a structured, deliberate and methodical mode which does reiterate every single stage of the Life Cycle. SDLC in 1960s was originated to develop very large scale systems with heavy data processing units and routines [18]. There are many different types of SDLC models. Some of these are:

- Waterfall Model
- Rapid Prototyping Model
- Fountain Model

- Build and Fix Model
- Spiral Model
- Synchronize and Stabilize Model
- Incremental Model

The most suitable model is selected on the basis of type of system to be developed, requirements and functionalities of the system, skills and experience etc. A suitable SDLC is a key to the success of project.

2.2.2 Importance

There was a time when the systems were created by simply taking requirements and directly implementing those to get the results but now a days the systems have become so complex and big that a complete team of analysts, architects, testers, programmers and users is necessary to work together and create a successful and error free system. A SDLC is also compulsory to achieve following goals:

2.2.2.1 High Standard System Creation

It is very essential to use a SDLC model to develop a system as it is now a days very important that the product delivered must be of high quality. An average system can be easily created without going into the details of product quality but it will be of not much use due to its low quality. Hence to deliver a high quality product a system must be developed using a SDLC model.

2.2.2.2 Easy Handling and Control over Implementation

A SDLC model is necessary for the development of a successful system as it helps in keeping track of all the requirements and functionalities already completed and to be completed. Also there could always occur some error or bug after the completion of implementation hence strong documentation of every single thing helps in keeping track of each functionality of system.

2.2.2.3 Fulfilment of User Needs

The final product of every system must fulfil all the needs or requirements of the user of that system. If a system is working great but it does not have the basic functionalities user demanded

then it is of no use. Hence SDLC helps to make sure the user needs fulfilment and even the addition of some extra functionality.

2.2.3 Phases

There are multiple phases of a system development life cycle and the output of one phase becomes the input for the next phase. Also these phases are not necessary to be carried out sequentially. If the phases of life cycle are not dependent upon each other then they can be merged or can be implemented in parallel to meet the deadlines.

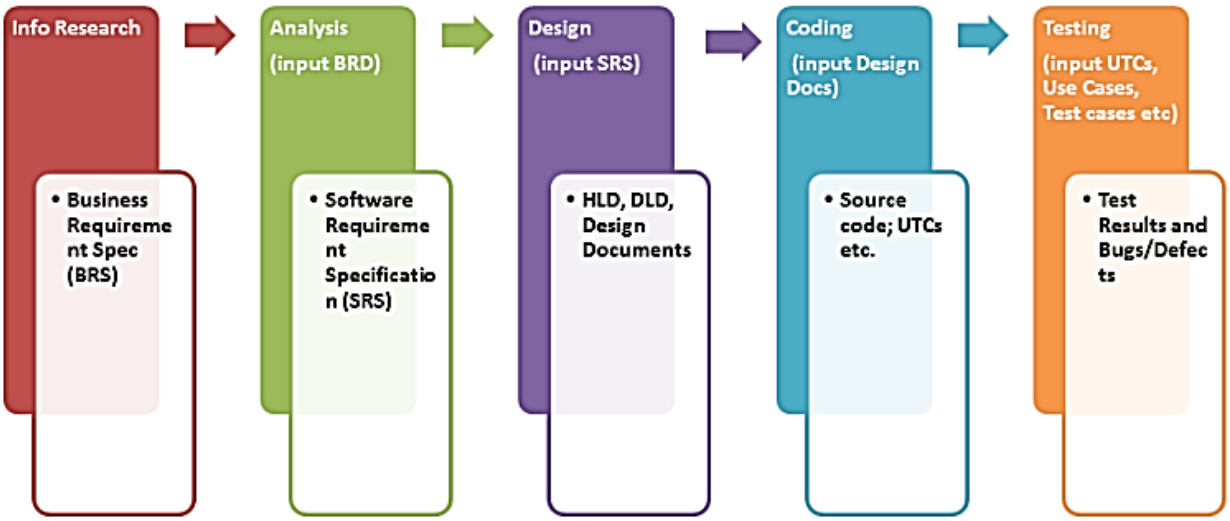

Figure 2.3: Documents Generated after SDLC Stages[45]

A document is generated after each stage of SDLC. Figure2.3 shows some of the documents generated after each stage of SDLC. Following are some details of essential phases of a SDLC model:

2.2.3.1 Feasibility Study and Planning

This stage checks that whether it is possible to achieve the defined goals of the project or not. Also it does make high level plans about the goals to be achieved at the end of system development. Generally it creates a high level view of the whole system.

2.2.3.2 Requirement Definition and System Analysis

This stage further refines the goals of the project and after the analysis of the user needs it decides that what functionalities are to be added in the system.

2.2.3.3 System Designing

This phase in detail defines the operations and features desired in the end product. This phase also includes formation of process diagrams, screen layouts, pseudo codes, business rules and other kinds of documentations.

2.2.3.4 Implementation

The real implementation and coding is done at this stage of SDLC.

2.2.3.5 Integration and Testing

This stage brings all the unit components together and integrates for the interoperability and system testing of these components. These components are also tested one by one i.e. unit tested to find errors and bugs.

2.2.3.6 Installation, Deployment and Acceptance

This one is the final phase of the initial development cycle and system is installed into the actual working environment and is checked for acceptance by the users of the system.

2.2.3.7 Maintenance

This one is the most important part of SDLC as it includes additions, changes, corrections, compatibility issues handling with other platforms etc. This phase which does seem least glamorous goes on for the rest of system life.

CHAPTER 3: State Of Art and Previous Techniques For Fovea Localization And Macular Edema Detection

Computer Aided Diagnosis systems are very helpful to physicians in taking human error free decisions about diagnosis of any disease. Automated Fovea Localization and Edema Detection system through OCT analysis is also a new system which helps a lot in taking diagnosis decisions and hence saves a lot of time and minimizes the chance of error. Here is an overview of other techniques already established for the same purposes:

3.1 Fovea Localization Related Work

AMD related many diseases can be identified through the localization of Fovea and Optic Disk and there is much work done in this regard for fundus image and there are many different algorithms which can localize fovea and optic disk in fundus images with very high accuracy.

There are multiple methods proposed for the detection of fovea in fundus image. One is the detection of fovea in fundus images is by using some morphological operation of Image processing. It finds out the location of optic disk first and then identifies the location of fovea. Since fovea is the non-vascular region of fundus image that's why it is the dark most part of the image. In this way a collection of pixels located at the center and dark colored are marked as fovea [19].

Spatial domain filteration is another method which is used for the detection of fovea. Various gray scale image operations are applied on the fundus image first. Then spatial filteration is applied to extract the macular region. After that fovea is identified as the lowest frequency values in the Macula [20].

Since fovea is the non-vascular region of macula and does not have any blood vessels. By using this property of fovea another technique has been proposed for fovea identification. It identifies the presence or absence of fovea on the basis of blood vessels presence or absence. The thickness of blood vessels is calculated in macula and the region with minimum thickness is considered as fovea [21]. Another method for detection of fovea in fundus images is with the help of color bands. A moving window calculates the average color intensity of the image after the extraction of red and green components of fundus image. The window having minimum average intensity value is marked as fovea. These intensities are calculated after the fusion of red and green components [22].

By using the properties of blood vessels and information of optic disk in fundus image, another algorithm based upon optic disk is also proposed [23]. Graphically represented intensities of color bands are also helpful in the detection of optic disk and fovea region [24].

The extraction of retinal layers is also very important before fovea detection in OCT images and there are many methodologies proposed for this. One method is the assigning of normal feature values for all the layers. Then for a given image, scanning is done vertically. When the values of features start to deviate from present values then it is checked in the next layer. If this condition meets then it is marked as the separation mark between the two layers [25].

Probabilistic model is another one for the extraction of the layers. A probabilistic value for each pixel in the layer is calculated after some preprocessing. The value of layer defines the probability of the pixel to belong to that layer. If the value of layer is high then the pixel will more probably belong to that layer. This is done by using random forest classifier which separates it into layers [26].

Due to tilted OCT images during scanning, it becomes sometimes difficult to process the image easily so the alignment of image is very necessary. The flattering of layers aligns them to the x-axis and then bilinear interpolation can be easily used for image alignment [27][28].

3.2 Macular Edema Related Work

There is no work already done for the detection of Macular edema in OCT images. But there are many methods defined for the identification of Macular Edema in Fundus images. There are many different methodologies proposed for the detection of Macular Edema and related diseases in fundus images [31-34]. There are mainly two methods for the detection of Macular edema. One is the direct examination and the other is indirect method in which Macular Edema is detected on the basis of Exudates presence in retinal fundus images. Some of the methodologies of macular edema detection are:

One method for the detection of Macular Edema in fundus images is through the detection of exudates in fundus images. In this method first of all the detection of Optic Disk is very necessary and it has been done by the use of morphological filteration techniques and watershed transforms. After that exudates have been found by their high variations in their gray levels and morphological re-construction techniques have been used to determine their contours. Finally Macular Edema detection has been done on the basis of exudates presence [29].

In another method for the detection purpose of Macular edema it is necessary to find the presence of all of the possible exudates on retinal surface. In this method the exudates have been enhanced with the help of Gabor filteration bank and a binary mask has been generated for the possible locations of exudates. Hence the Macular edema has been identified on the basis of number and locations of exudates on the surface of retina in colored fundus images [30]. Table3.1 shows an overview of all the related work done.

Table 3.1: Overview of Related Work

Authors	Methodology
Asim, K.M., Basit, A. , Jalil, A. [19]	Morphological Operations and Darkest Pixels based localization of fovea in fundus images with 97.29% Accuracy.
Guven, A. ; Oner, A.O. ; Kara, S. [20]	Spatial Domain filtering based localization of fovea in fundus images.
Ziyang Liang ; Wong, D.W.K. ; Jiang Liu ; Ngan-Meng Tan ; Xiangang Cheng ; Cheung, G.C.M. ; Bhargava, M. ; Tien Yin Wong [21]	Blood Vessels thickness based identification of fovea region with 86.53% Accuracy.
Veras, R., Silva, R. ; Aires, K. ; Medeiros, F. [22]	Average Color Intensity based identification of fovea in fundus images with 81.12% Accuracy.
Kovacs, L. ; Qureshi, R.J. ; Nagy, B. ; Harangi, B. ; Hajdu, A. [23]	Optic Disk based localization of fovea in fundus images.
Yogesh Kumar A., Sasikala M [25]	Manual Feature value assigning and vertical scanning based extraction of retinal OCT layers.
Andrew Lang, Aaron Carass, Elias Sotirchos, Peter Calabresi, and Jerry L. Prince [26]	Probabilistic model based segmentation of retinal OCT layers.
Yang Q, Reisman CA, Wang Z, Fukuma Y, Hangai M, Yoshimura N, Tomidokoro A, Araie M, Raza AS, Hood DC, Chan K. [27][28]	Bilinear Interpolation based Alignment of OCT images.
Thomas Walter, Jean-Claude Klein, Pascale Massin, and Ali Erginay [29][30]	Exudates identification based classification of Macular Edema with 97.59% Accuracy.

3.3 SDLC Models

Waterfall is the oldest SDLC model and is different from others due to the reason that it does work sequentially from requirements gathering to the maintenance of system. This model is suitable for the type of systems where the requirements or functionalities of the system are fixed as in this model it is not allowed to change the requirements of the system after the requirements gathering stage has passed. Figure3.1 gives an overview of classical waterfall model.

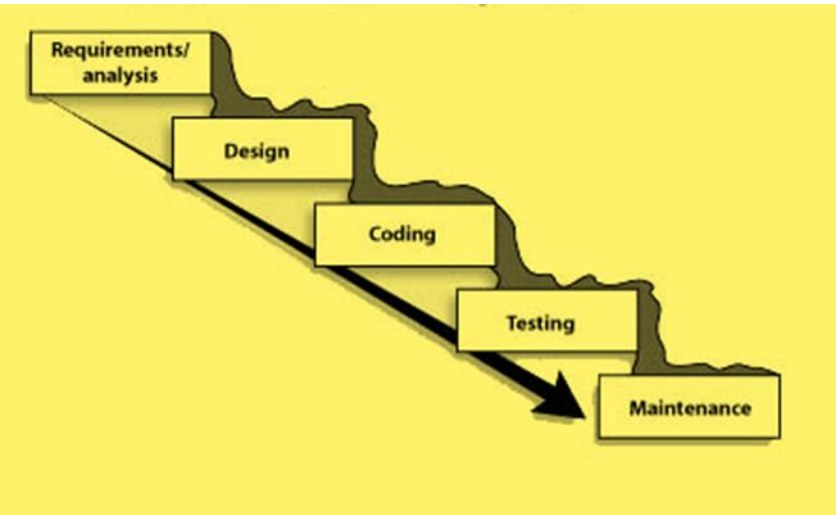

Figure 3.1: Waterfall Model[46]

To reduce the weakness of the waterfall model many other SDLC models were designed and the concept of iterations of life cycle was introduced. In Spiral model, a development teams starts developing a system with some initial requirements except for installation and maintenance phases and develop a prototype model. After finding out the limitations and missing functionalities of the system, all the phases of life cycle are repeated unless it does meet the needs of the user. Increasing “Spirals” add the new functionalities in each iteration. Spiral model is helpful in those types of systems where all the requirements or functionalities of the system are not already known. Figure3.2 is an overview of spiral model.

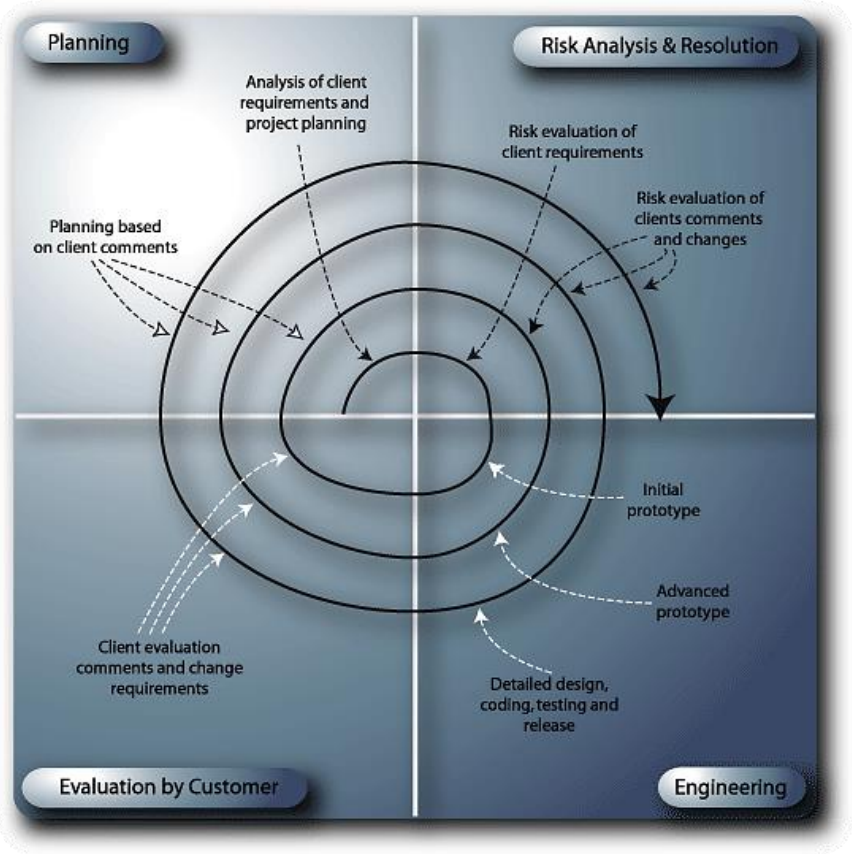

Figure 3.2: Spiral Model[47]

Top Down Model is another one which was introduced by IBM in 1970s. In this model, high level functionalities are first implemented and after that the low level functionalities are added to the system. It is a good fit for the projects in which the already developed functionalities cannot be added and the whole new system has to be developed. Hence it will be good to develop main high level functionalities first and the sub level functionalities to be added at a later stage. The major problem with this model is that the system cannot be tested until its low level functionalities are complete and if there was an error generated at the first step of development then it will be almost impossible to find the error. Figure3.3 is an overview of top-down model.

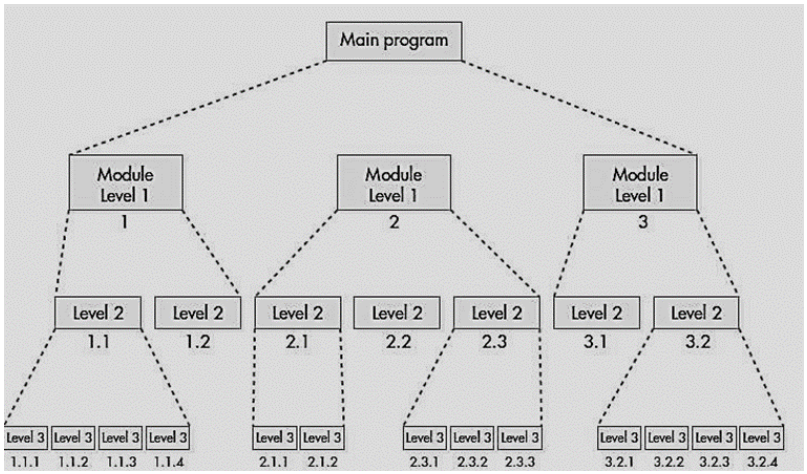

Figure 3.3: Top Down Model

Bottom Up Model is another type of model in which low level components are developed first and then these are combined to form the complete system but it is very difficult to coordinate and make sure that the system will work properly after the integration.

Hybrid model is the one in which most of the development is done according to top down approach but in the meantime high risk components are developed in parallel and if a problem is found with these components then they can be modified. It is good for the type of projects in which some new functionality is to be developed and there is no guarantee of it to be working.

Figure3.4 Rapid Prototyping is the type of model in which quick prototypes are made and delivered to provide a quick response. It works very fast and does miss some of the steps of SDLC. Since it is made and delivered so quickly then it does not gets tested properly.

In Object Oriented Model, the objects are defined and can be reused which saves a lot of time and coding. Plus point is that it can use many object oriented designing concepts like encapsulation etc. But it is very difficult to handle as some mistake in class hierarchy can destroy everything [35].

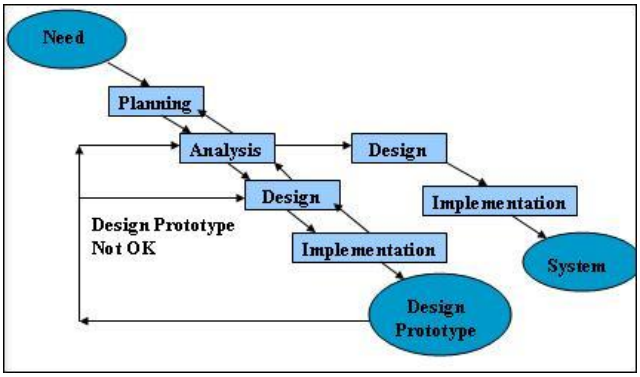

Figure 3.4: Rapid Prototyping

CHAPTER 4: Testing Based Rapid Prototyping Model for Fovea and Edema Detection

4.1 Background

Rapid prototyping is the type of SDLC model in which quick prototypes are delivered for assessment and after doing requirements modifications, a new prototype is again developed according to new requirements. Following steps in Figure4.1 are followed during this process.

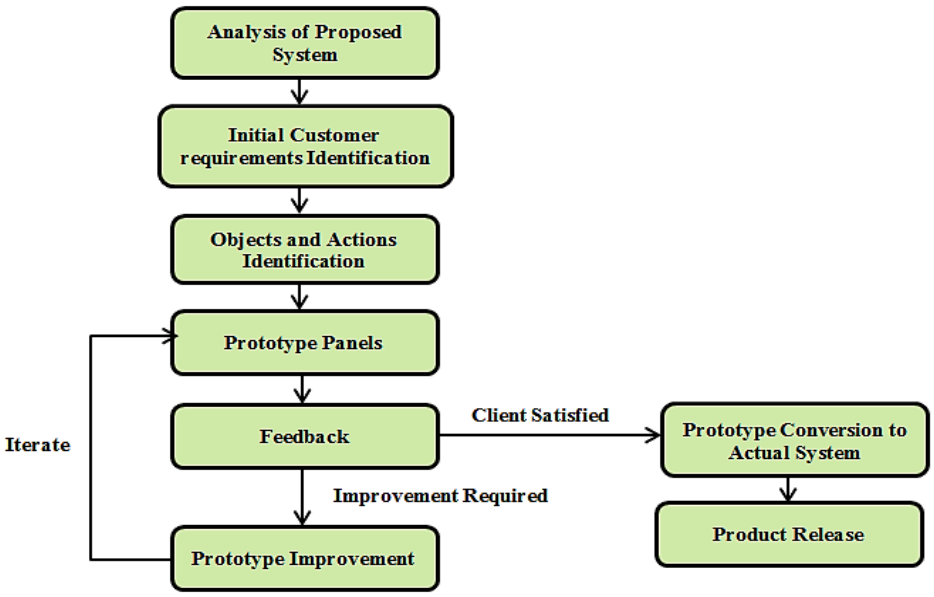

Figure 4.1: Rapid Prototyping Process

4.2 Overview

Fovea and Edema detection system is aimed to provide highly accurate fovea and edema detection and for that it is necessary to get quick and frequent response from a specialist which is at the end will be using this system. Rapid Prototyping Model is the one which can provide help in development of a system in this way. Hence the development of this system is done using this SDLC model. The whole project development is divided into multiple modules and their sub modules. A prototype module is developed for each module and is handed over to a specialist for feedback. The changes mentioned by the specialist are noted and another prototype is developed on the basis of changes identified. Once the prototype of the changed requirements is completed, it is again handed over to the specialist for feedback and this process goes on as long as the

physician gets satisfied with the prototype delivered. This process is repeated for all individual modules. After the entire prototype modules are approved, the final development is done for the improvement of quality measures of the system. In this way Rapid Prototype is helping in the development of a highly reliable system which is being verified by the user after each single step and the error cost is reducing very much since all the errors are being removed with the development of every next prototype.

4.3 Development Flow

Following steps are to be followed during the development of system.

- Requirements Elicitation
- Requirements Specifications
- Architectural Design
- Implementation
- Testing
- Feedback form Specialist
- Improved Prototype Systems development until approval from user
- Improvement of Quality of Final prototype
- Deployment
- Maintenance

Figure4.2 shows an overview of flow of development from requirements gathering to the completion and maintenance of system.

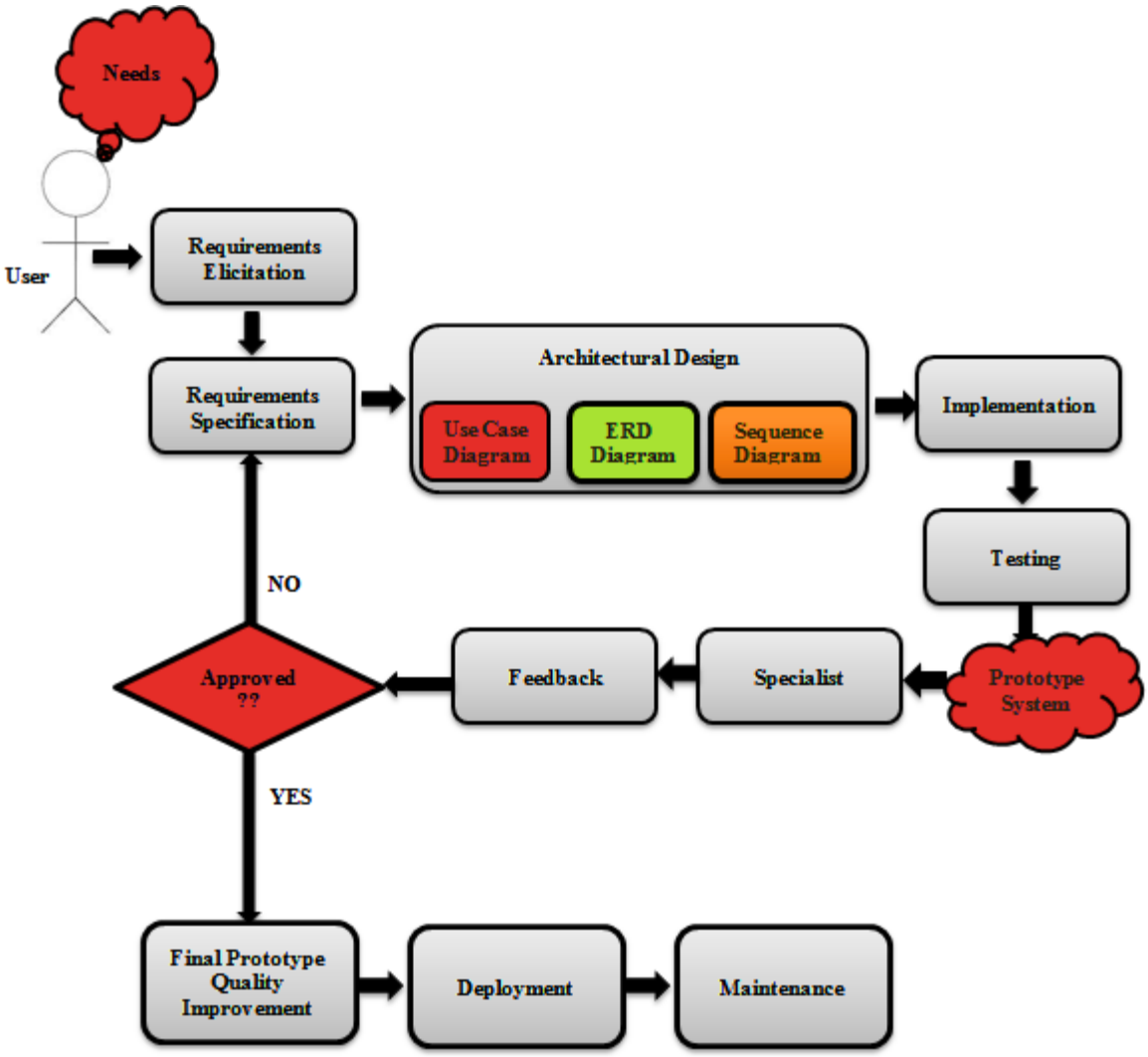

Figure 4.2: Rapid Prototyping Flow Diagram

4.3.1 Requirements Elicitation

Requirements Elicitation is the first most step of any project development. In this step maximum number of possible requirements are tried to collect. These requirements are not in a well written and structured form but this is the step where most of the information is collected about the system under development. The requirements for this project are collected from the Ophthalmological Department of AFIO. Out of multiple techniques of requirements elicitation e.g. Brainstorming, Interviewing, Questionnaires etc. , the requirements for this project are collected through the Interviewing technique. Many interviews are conducted with the potential users and stakeholders of the project and maximum number of requirements are collected for the project. Following information about the product has been collected after all the interview sessions:

- The system is to be developed for AFIO.
- The Ophthalmological department will be using this system.
- An Ophthalmologist, Subspecialist and Surgeon will be using this system.
- A successful system will be very much helpful economically and will prompt others to use the same system.
- Any similar system is not already available.
- The system is to be completed within 18 months.
- Resources i.e. Data Sets of Images of Fovea and Macular Edema are limited due to confidential records of patients.
- There must be a milestone defined for after each month and a prototype must be delivered after each month.
- A good solution for the localization of fovea is through the localization of ILM retinal layer and a good solution for Edema detection is through the analysis of localized fovea region.
- The system is trying to address the problems that Fovea localization is not already done in OCT images as Fovea localization helps in identification of multiple diseases. Also it deals with the problem of detection of Macular Edema in OCT images.
- The system is to be used on windows Operating system.
- The system must be very fast and must provide the analysis results within seconds.
- It must give accurate results. Accuracy of results is a very critical point.
- The system must be compatible with the integration with Legacy system.
- In future the system may be evolved for some other related diseases.
- The system may be flexible with the time required for processing as long as it is providing accurate results.
- The system must be flexible enough to deal with corrupt scan images at some level.
- The information is provided by an Official person.
- Details about project at this level are correct.
- The members of system usage team are willing to have such a system.
- No one's job is threatened by this system as the system is to help people in doing their job not to replace someone.

- Analysis is to be done of OCT images.
- The system has to find ILM layer in OCT images.
- The system has to localize Fovea region on ILM layer.
- The system has to identify whether or not Fovea is present in the image.
- The system has to find the presence or non-presence of Macular Edema on the basis of fovea region analysis.
- The system must localize Fovea within 12 months and must detect Edema in next 4 months.
- There are multiple methods possible for Fovea localization.
- The data set images must be preprocessed for noise removal and image enhancement.
- The input of the system is an OCT image and the output of Fovea localization is also an OCT image with labeled fovea point and for edema the result is a dialogue box showing the presence or no presence message of Edema in OCT image.
- The results of labeled fovea point and status of edema is to be saved in Database for later record and usage.
- The equipment is to be located in the OCT Scanning Lab.
- There is only one location for the equipment keeping.
- There are no environmental restriction on the system like humidity and temperature.
- The system has to have enough memory for the records storage.
- The system is to be developed in Matlab.
- The input is coming from an OCT scan system.
- Output is going to store in the system database.
- Both input and Output images are to be OCT scans.
- The results are to be stored in a proper format for later understanding and trends analysis etc.
- The system standards must be enough for quick processing and results storage.
- The system has to response quickly, have very high processing speed and provide accurate results.
- The system must work 20 hours a day with no failure or crash and sequentially do all the processing.

- All the scans are to be processed one by one.
- The system is to be very user friendly and is to be secure enough to avoid any kind of misuse of the system.
- The system is to be protected for the access of records and each user's data is to be stored separately.
- User programs are to be separated from operating system and other programs.
- The system is to be backed up.
- The backup records are also to be stored on another location.
- Maintenance includes only includes error corrections not the system improvement.
- The system is to be compatible with other platforms but not with other operating systems.
- The system is to be accurate minimum 90%.

4.3.2 Requirements Specification

Requirements Elicitation is the stage in which requirements are gathered roughly and are structured properly. In requirements Specification stage requirements roughly gathered are studied deeply and their feasibility is estimated and on the basis of feasibility of each requirement three different categories are defined for a structured view of requirements. Three types of requirements are:

4.3.2.1 Functional Requirements

- The system has to find ILM layer in OCT images.
- The system has to localize Fovea region on ILM layer.
- The system has to identify whether or not Fovea is present in the image.
- The system has to find the presence or non-presence of Macular Edema on the basis of fovea region analysis.
- The data set images must be preprocessed for noise removal and image enhancement.
- The input of the system is an OCT image and the output of Fovea localization is also an OCT image with labeled fovea point and for edema the result is a dialogue box showing the presence or no presence message of Edema in OCT image.
- The results of labeled fovea point and status of edema is to be saved in Database for later record and usage.

- The results are to be stored in a proper format for later understanding and trends analysis etc.

4.3.2.2 Non-Functional Requirements

- User interface of the system is to be designed according to the users of the system.
- The system has to be very fact and provide results within few seconds.
- The results must be very accurate.
- The system has to be compatible with legacy systems.
- The system has to be flexible enough to deal with healthy as well as corrupt scan images.
- The system has to have enough memory for the records storage.
- The system standards must be enough for quick processing and results storage.
- The system has to response quickly, have very high processing speed and provide accurate results.
- The system must work 20 hours a day with no failure or crash and sequentially do all the processing.
- The system is to be very user friendly and is to be secure enough to avoid any kind of misuse of the system.
- The system is to be protected for the access of records and each user's data is to be stored separately.
- User programs are to be separated from operating system and other programs.
- The system is to be backed up.
- The backup records are also to be stored on another location.
- The system is to be compatible with other platforms but not with other operating systems.
- The system is to be accurate minimum 90%.

4.3.2.3 Constraints Requirements

- The system is to be developed only for AFIO. It is not allowed to use their data set images for any other purpose.
- The system is to be completed within 18 months.
- Limited Data set images are available due to confidential records of patients.

- A milestone is defined after every month. A prototype is to be delivered after each month.
- The system is to be used on windows operating system.
- Only OCT images are to be analyzed.
- System is to be kept in a suitable environment.
- The system is to be developed in Matlab.
- The input is coming from an OCT scan system.
- Output is going to store in the system database.
- Both input and Output images are to be OCT scans.
- Maintenance includes only includes error corrections not the system improvement.

4.3.3 Architectural Design

Architectural design consists of high level and low level design of the system. It represents the whole system as a model. The model can be in different forms like Use Case diagram, Data Flow Diagram, Sequence Diagram etc. These diagrams also help in clarifying different confusions about any functionality or any other thing. These diagrams are given to the users of the system for an overview of the system to be designed and if there is any misunderstanding then it is modified at this point. Hence saves the time, effort and resources. These design diagrams also help the developer in keeping track of the development steps and also in error propagation and testing of the developed system.

4.3.4 Implementation, Feedback, Modifications

The whole project is divided into three modules.

1. ILM extraction
2. Fovea Localization
3. Edema Detection

There are also sub modules of each main module. Figure4.3 shows the division of whole project into different modules.

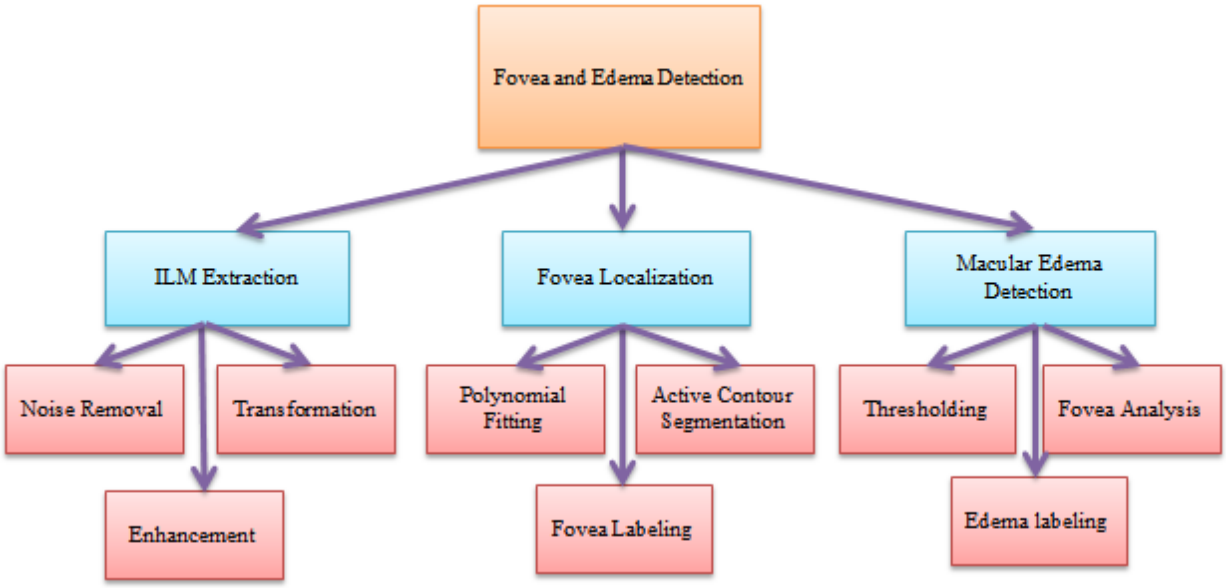

Figure 4.3: Modules Division

Since the modules are not independent but are each next module is depending upon the previous one. That's why three sub modules of main module are developed one by one. First of ILM Extraction module is developed by rapid prototyping. After 4-5 prototypes this module has been approved and finalized. After that the second module is developed by rapid prototyping. All the errors and bugs are removed with each next prototype. Similarly final module has been approved and finalized after some prototypes. Fovea localization and edema detection algorithms are changed many times as the results were either not good or were not acceptable by user. Rapid prototyping has helped in finally achieving a perfect system which is acceptable and according to the needs of user.

4.3.5 Quality Improvement, Deployment, Maintenance

Next thing is the quality improvement of the final product which is improved in terms of response. After this the system has been deployed and the integration with legacy system is improved in the maintenance phase.

4.3.6 Testing

Boundary Value Analysis is used for the testing of each module and each sub module. In boundary value analysis each functionality is tested by three input values. One is the normal

Image, Second is abnormal and third one is poor quality and corrupt image. Following is an example of test cases designed for testing in Table4.1.

Table 4.1: Test Case Example

Build Number	**P6_306**
Tester Name	Sadaf Sahar
Test Type	Integration test
Test Case Name	Fovea Localization Test
Test Case Number	TC004
Test Case Description	Testing that ILM extraction and fovea localization modules are working together.
Items To Be Tested	
1.	Check that system gives error if an image which is not OCT is provided.
2.	Check that it labels fovea in a fovea present image and prints No Fovea otherwise.
Specifications	
Input	**Expected Output**
OCT Image	Labeled fovea image in case of presence of fovea and No Fovea printed in case of fovea not present and an error in case of some non-oct image.
Procedural Steps	
1. Selection of three OCT image. **2. One having fovea, one having no fovea and third one not of type OCT.** **3. Check one by one on each image whether it labels fovea for fovea image and gives No Fovea for non-fovea image and error for Non-OCT image.**	

In this way all the functionalities are first unit tested for these three kind of images. After that sun modules are combined and integration testing is done. Finally System testing is done for the whole system. This testing phase is repeated after every single prototype development for the high quality and bug free system achievement. Since in many cases the Rapid prototyping model does miss some phases like testing mostly to provide the prototype quickly and making the quality of product risky but in my project I have done testing after the development of each single prototype to keep the system totally error free. Also the performance testing of final product after prototyping phase completion is done by its usability testing, stress testing, Recovery Testing etc. to increase the quality of end product.

CHAPTER 5: METHODOLGY

The main aim of the system under development is the conversion of an OCT image into a Fovea marked image and after that the labeling of that image as Edema or Non-Edema scan. Following processing is done from Input image to the conversion of Output image. Figure5.1 is an overview of Methodology steps.

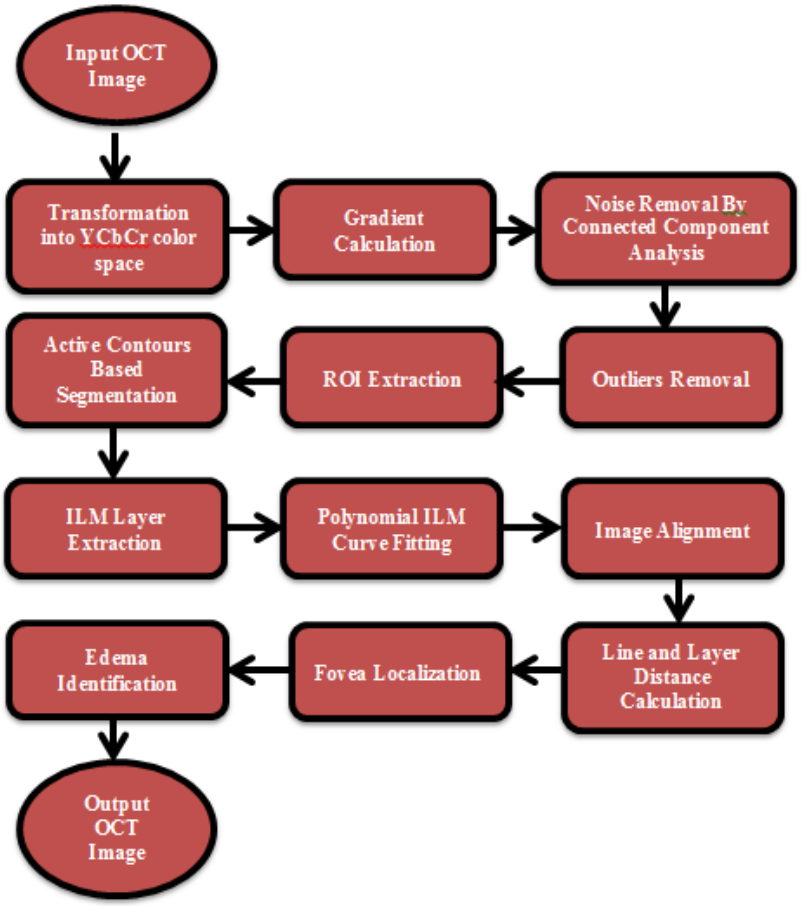

Figure 5.1: Methodology Flow Diagram

5.1 Input Image

An OCT image of moderate quality is taken as an input image. This system also works for Input Videos instead of Images. In case of videos the system extracts different frames of video and then does further processing on these frames. Figure5.2 is an example OCT image.

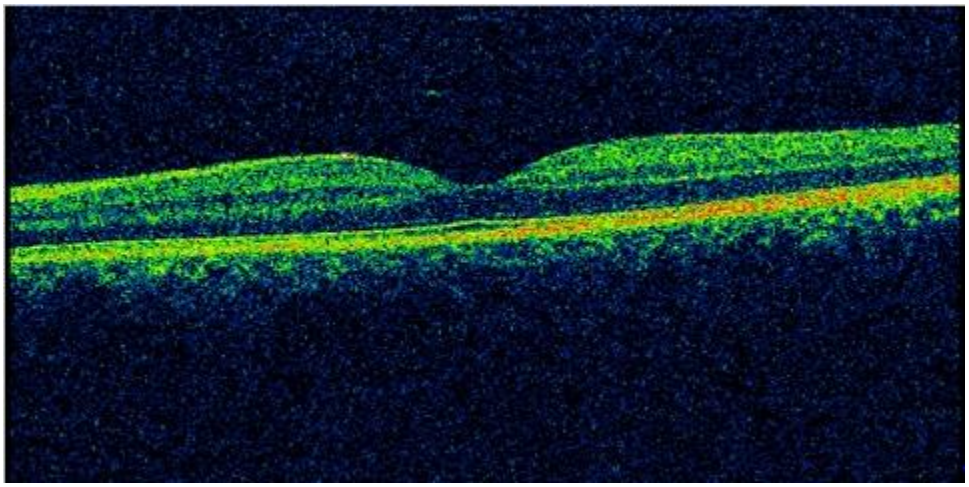

Figure 5.2: Input OCT Image

5.2 Color Space Transformation

The input image is in RGB color space. But in this color space it is not possible to extract scan region from background due to presence of blue components in both background and scan region. To extract the foreground region from background, input image is converted into YCbCr color space. In this color space, background can be very efficiently separated from foreground region. Figure5.3 is an example of input image conversion into YCbCr color space transformation.

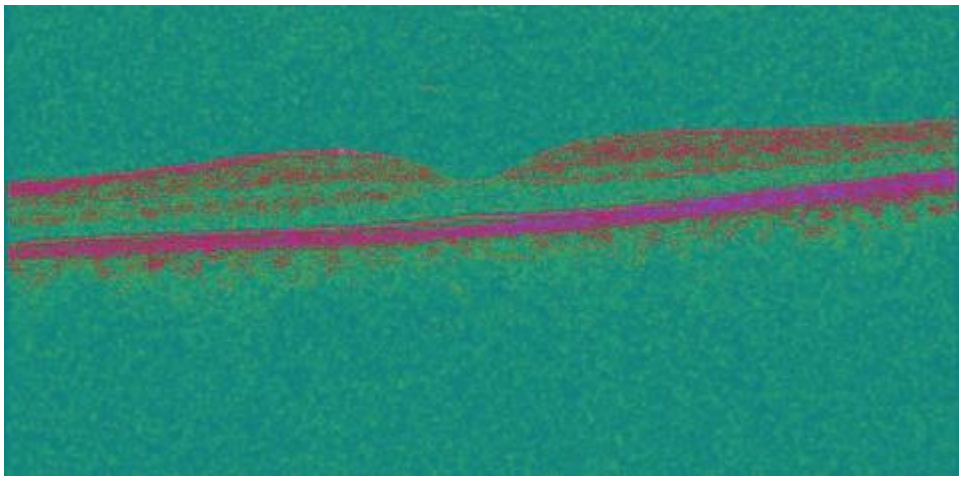

Figure 5.3: Transformed input Image

5.3 Gradient Calculation

Since the aim is to extract out the Outer most boundaries of OCT scan image as these boundaries help in identification of multiple disease. In this project the aim is to localize fovea and Edema and both these are concerned with top most retinal layer i.e. ILM layer. Hence the focus is to extract out ILM boundary with maximum accuracy. For that purpose the gradient of YCbCr

domain image is calculated by using Prewitt operator for each color component. The three gradient images are obtained as a result. Each of three is for one color component.

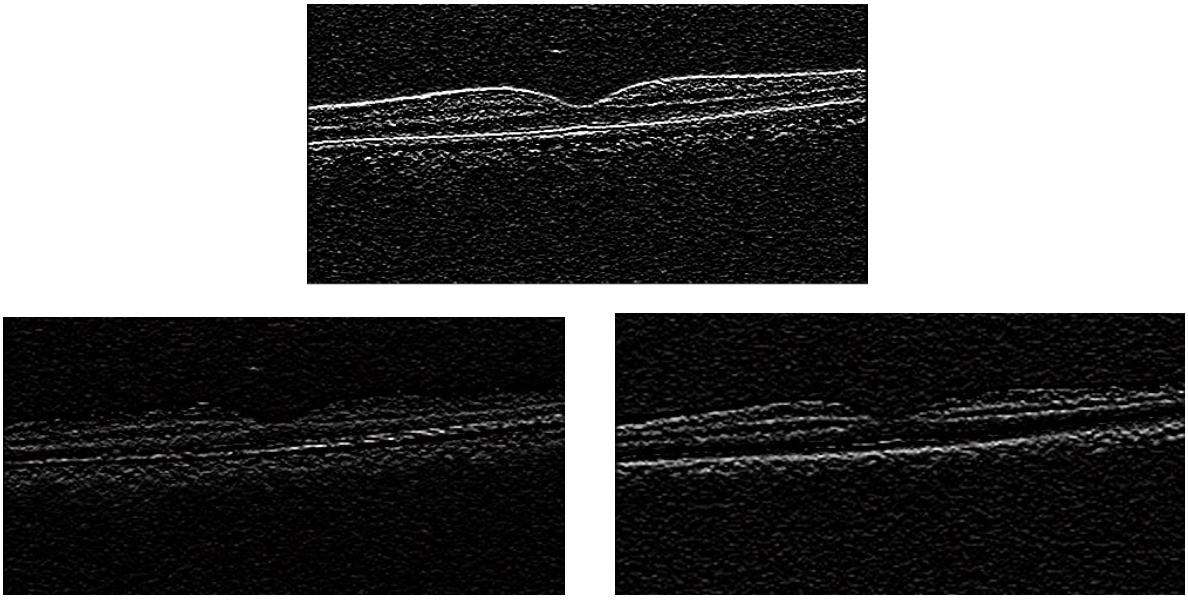

Figure 5.4: (Top) First Component Gradient, (Bottom-Left) Second Component Gradient, (Bottom-Right) Third Component Gradient

The three gradients in Figure5.4 are for the three color components. These boundaries of top and bottom layer can be estimated from these gradients. The top gradient is of Red component which is contributing the most and is providing most of the information about layers boundaries. A gradient image by combining all the three gradient images is generated for further processing.

5.4 Noise Removal

Noise has been removed by first applying a threshold on the gradient image which converts the image into a binary image and removes some noise. Figure5.5 is the binary image after Thresholding.

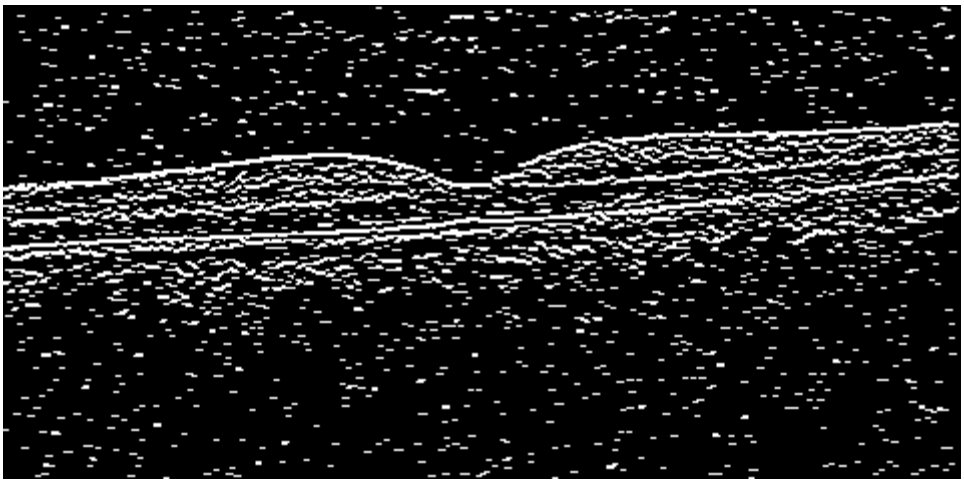

Figure 5.5: Binary Image

Further noise has been removed by applying Connected Component Analysis on the image. In connected components algorithm, the connected components which are greater than a threshold are kept and small objects are removed which are of no use. In this way small objects which are kind of noise in this case are removed by removing smaller than threshold objects. Figure5.6 shows the noise free image after connected component analysis. Much noise has been removed after this step.

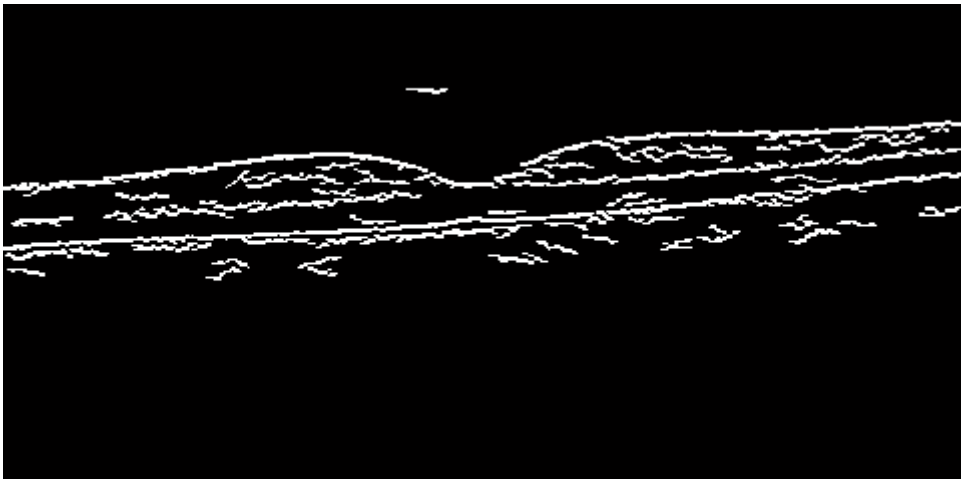

Figure 5.6: Noise Removal By Connented Components Analysis

5.5 Outliers Removal

After removing noise by removing small connected components, there are some small objects still present which are greater than threshold value. These small objects are still part of noise. The removal of these small objects is also necessary for area extraction of exact layers. These small objects are removed by calculating the distance of each small object centroid from the biggest object centroid. Figure5.7 is an OCT image with centroids of each object labeled.

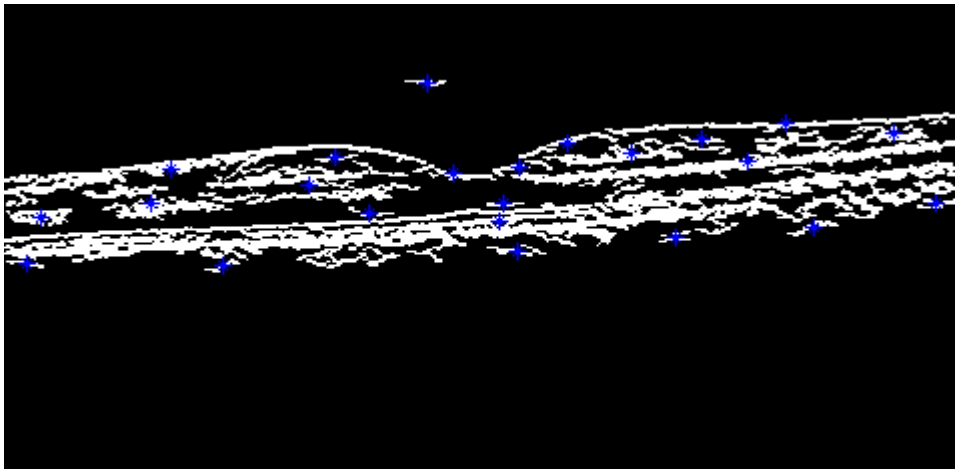

Figure 5.7: Centroids Labeled OCT

If the small object is at a distance greater than a threshold value then the small object is considered as an outlier and is removed from the image. In this way a completely noise free image is achieved which can now be used for further processing. Figure5.8 shows a noise free image after outliers removal.

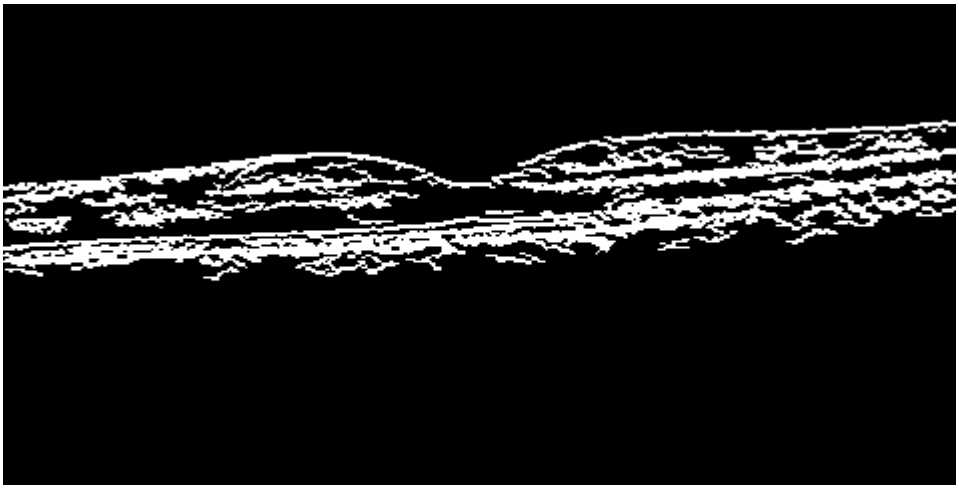

Figure 5.8: Noise Free Image

5.6 ROI Extraction

Upper and Lower layer boundaries are extracted out of noise free image for Fovea localization in upper ILM layer. Figure28 shows the upper and lower most layers separated. After layer extraction, the segment of original image between layer boundaries is extracted. Figure5.9 is the segmented Region of Interest. This region of interest is further used to extract out exact layers from original image.

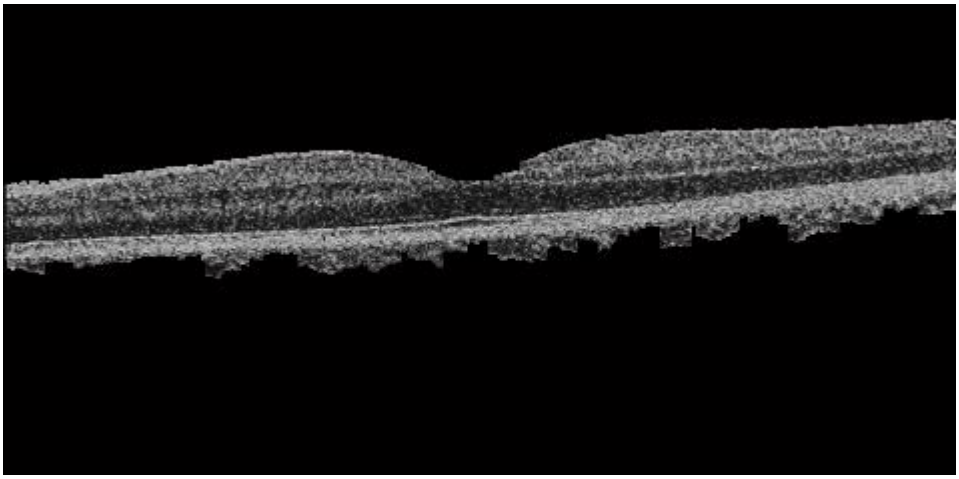

Figure 5.9: Region Of Interest

5.7 Active Contours Based Segmentation

Extraction of exact layers area is a challenging task out of region of interest estimated. For this purpose multiple techniques are tested but best results are achieved by using Active Contours Based Segmentation.

5.7.1 Active Contours Model

Snakes model or Active Contours model is a type of spline structure model which works on the basis of Energy Minimization rule and is used to extract the outline of an image from an initial rough mask of image boundaries. The algorithm takes an initial snake mask and then tries to wrap it around the edges and contours of the image. Figure5.10 (left) shows an initial snake and figure5.10 (right) shows the snake after wrapping around the image and highlighting of contours.

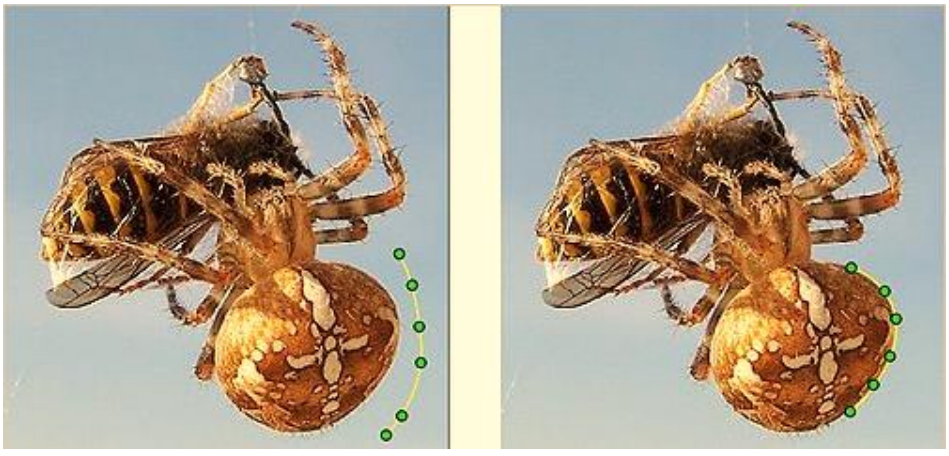

Figure 5.10: Snake Model Working[48]

External forces of initial mask try to push the mask towards the actual boundaries and internal forces try to pull it towards the actual boundaries. This wrapping of initial mask around original

boundaries takes place in multiple iterations. The principle behind this wrapping is minimization of snake energy.

An initial snake is a sum of n different points which are further improved to fit in the actual edges and contours, the internal energy $E_{internal}$ in Equation5.2 and the external energy $E_{external}$ in Equation5.3. The internal energy is responsible for the deformation of the initial snake and the external energy is responsible to fit the snake onto the original image. The external energy is the sum of Image forces E_{image} and user introduced constraint forces E_{con}. The internal energy is the sum of contour continuity E_{cont} and contour smoothness E_{curv}. The total energy of a snake is the integral sum of external and internal energy as shown in Equation5.1.

$$\mathbf{E_{snake} = \int_0^1 E_{internal} + E_{external}} \quad \mathbf{(5.1)}$$

Where

$$\mathbf{E_{internal} = E_{cont} + E_{curv}} \quad \mathbf{(5.2)}$$

And

$$\mathbf{E_{external} = E_{image} + E_{con}} \quad \mathbf{(5.3)}$$

The internal energy factor deals with the sensitivity of stretching of the snake and the curvature of the snake and hence deals with the shape of snake. Also some weight is assigned to each of the energy factor and it is necessary to choose a suitable value for each assigned weight. If a large weight is assigned to the continuity factor then it does penalize the changes to be made in the distance between contour points similarly if a large weight is assigned to the smoothness factor then it does penalize the oscillations in the contour and the contour starts acting as a thin plate.

Similarly the external energy forces deals with some other factors. The image energy is a function of features of the image. In an image, different lines, terminations and edges are the features of the image. The weights assigned to these features play an important role in the snake deformation.

$$\mathbf{E_{image} = \omega_{line} E_{line} + \omega_{edge} E_{edge} + \omega_{term} E_{term}} \quad \mathbf{(5.4)}$$

Where $\boldsymbol{\omega}_{line}$, $\boldsymbol{\omega}_{term}$ and $\boldsymbol{\omega}_{edge}$ in Equation5.4 are the weights assigned to the features. Larger weights cause the prominent features to contribute more in the image force. Constraint energy is

the user defined energy to guide the initial snake towards the convergence of some features. This is a user interactive term in which cannot only define the initial snake position but also guides the snake in terms of energy assignment.

All these energy factors help in the minimization of total energy and hence leads the snake to wrap around the original contours. This one is the default method which does have some corner cases and limitations. These limitations can be improved by some improved models. Gradient Vector Flow (GVF) is the model which deals with the convergence and wrapping of snake around concave shapes and the convergence of snake if defined at far location from the minima initially. These both are the limitations of default model which GVF deals with.

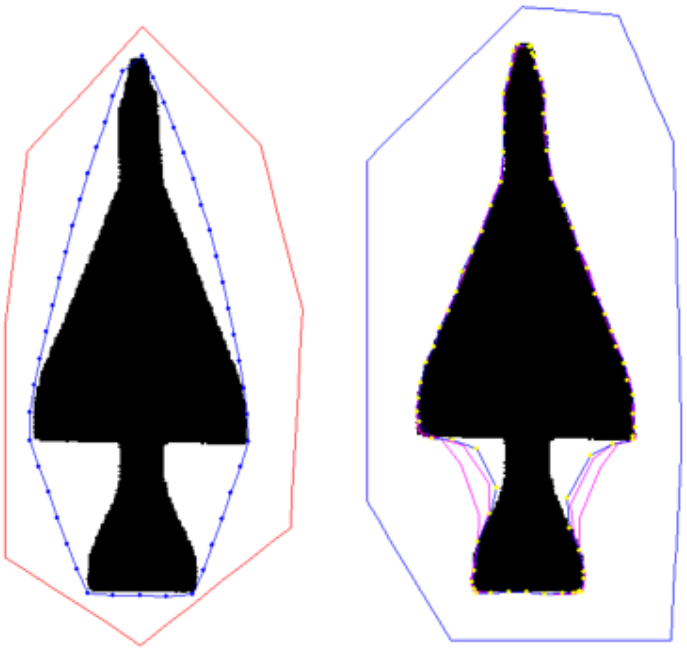

Figure 5.11: (left) Default Model Result, (right) GVF Model Result[48]

Figure5.11 (left) shows the result of a default Snake Model in which outer boundary is an initial snake or mask and inner boundary is the result after segmentation. The default model is unable to capture the concave boundaries. Similarly Figure5.11 (right) inner boundary is the result of GVF which is also segmenting out the concave boundaries.

5.7.2 Segmentation

The region of interest boundary extracted out in previous step is used as the initial snake or mask. This mask wraps around the exact layer boundaries and gives perfect ILM and Bottom layer extracted out of image. Figure5.12 is the OCT image extracted after Active Contour Based segmentation. Layers boundaries are very much accurate after segmentation.

Figure 5.12: Segmented OCT Image

5.8 ILM Layer Extraction

Out of segmented image, the ILM layer has been separated out since it is going to be used for the fovea localization purpose. Figure5.13 is the ILM layer of the segmented image.

Figure 5.13: Extracted ILM Layer

5.9 Curve Fitting

There can be some small holes and outlier points present in the ILM layer after segmentation. To convert this layer into a smooth layer, some curve fitting technique is necessary to apply on it to get a smooth layer boundary. There are multiple techniques for fitting a curve on a data of points. Some of curve fitting techniques are:

5.9.1 Interpolation

It is the classical method for fitting data points. It does fit the data very efficiently but it does work only on the data which is following a linear trend and the data which is not scattered. It simply takes two consecutive data points and draws a straight line between these two points. Figure5.14 shows the working of interpolation.

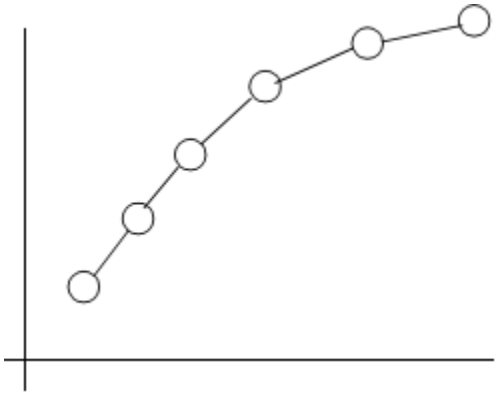

Figure 5.14: Linear Interpolation[49]

5.9.2 Linear Regression

It is another technique for fitting data points. It draws multiple straight lines between data points to separate them first. Then it calculates the distance of each line from the data points and the line having total minimum distance from data is taken as the line representing the data. Figure5.15 shows the working of linear regression.

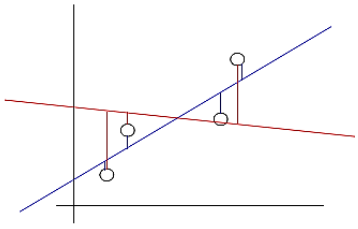

Figure 5.15: Linear Regression Working[49]

5.9.3 Linear Curve Fitting

This technique aims to represent the data to be fitted by a single function. It does fits the scattered data but if data is very much scattered then it tries to make a single function to fit this data and hence data fitting is not so good as a result of this type of fitting. Also it fits the data in a linear model which is not good for curved data. Figure5.16 shows the working of linear fitting.

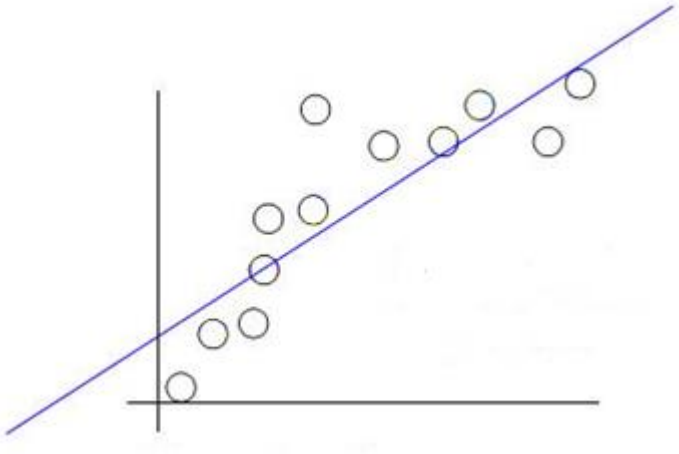

Figure 5.16: Linear Curve Fitting[49]

5.9.4 Polynomial Curve Fitting

This method also draws multiple lines to fit the data points but instead of joining two points with a straight line it uses a curve to join two points. The order of polynomial to draw the joining curve is to be specified efficiently as it is playing the major role in fitting data. At the end the curve which is at the minimum overall distance with data points is considered as the best fit. Figure5.17 is the working of polynomial curve fitting.

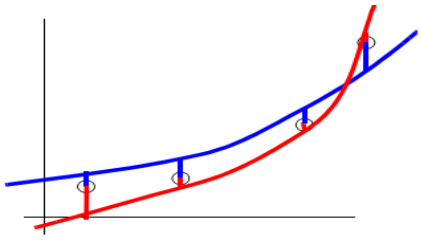

Figure 5.17: Polynomial Curve Fitting[49]

Polynomial fitting is the one suitable for this scenario. It makes the ILM smooth and unbroken. Figure5.18 shows an OCT image with smooth ILM layer after polynomial curve fitting.

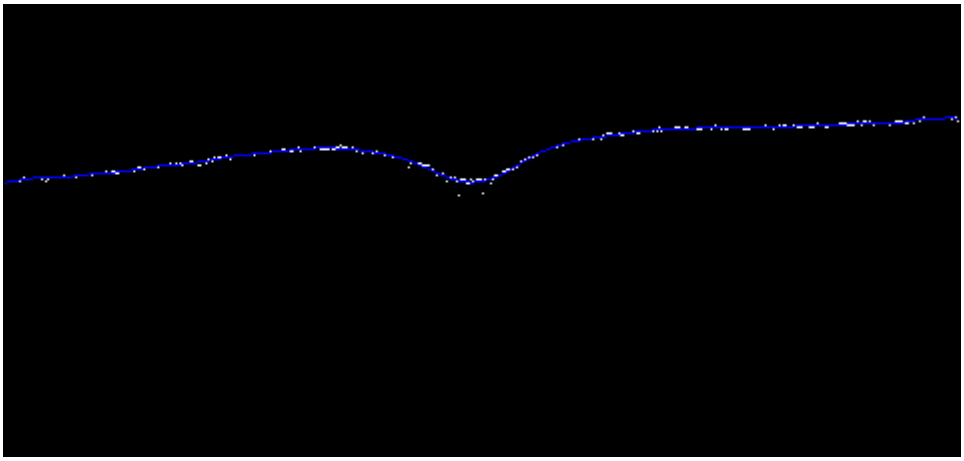

Figure 5.18: Smooth ILM Layer

In figure37, bottom layer is the un-smooth layer while top layer is the smooth layer after curve fitting.

5.10 Image Alignment

In some scenarios, the OCT image under processing can be tilted which creates problem during the fovea localization which is identified by the maximum dip point in the ILM layer. To deal with this issue, a straight line is drawn between two pints of ILM layer. These two points is taken at a far place from the fovea/central region of OCT image. The distance calculation for fovea point identification is now taken with respect to this straight line which makes the image act as a straight and aligned image. Figure5.19 shows an OCT image aligned by straight line method.

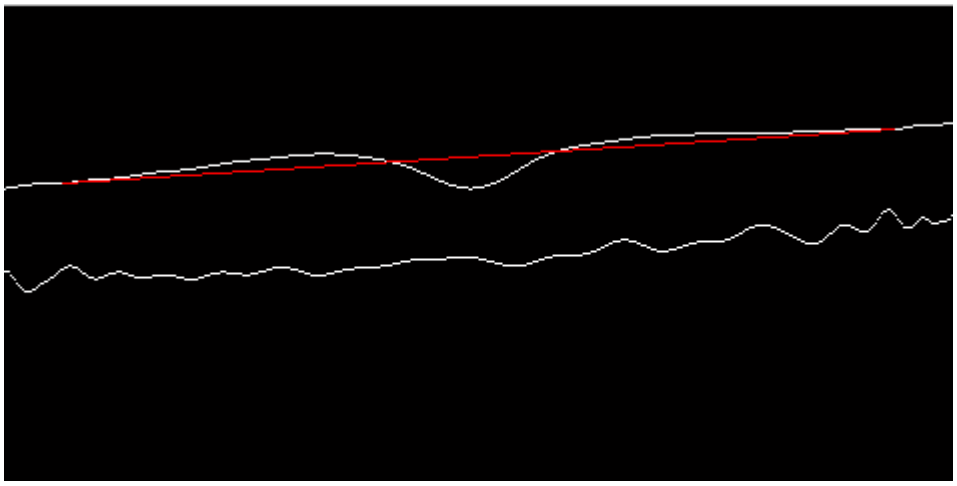

Figure 5.19: OCT Image Alignment

5.11 Fovea Localization and Edema Detection

Since Fovea is the maximum Dip point in the ILM layer central region. For that, the distance between the image aligning straight line and ILM layer smoothed by polynomial fitting is calculated and the point giving maximum negative distance between the line and layer is marked as fovea point. Figure5.20 shows an OCT image marked with Fovea.

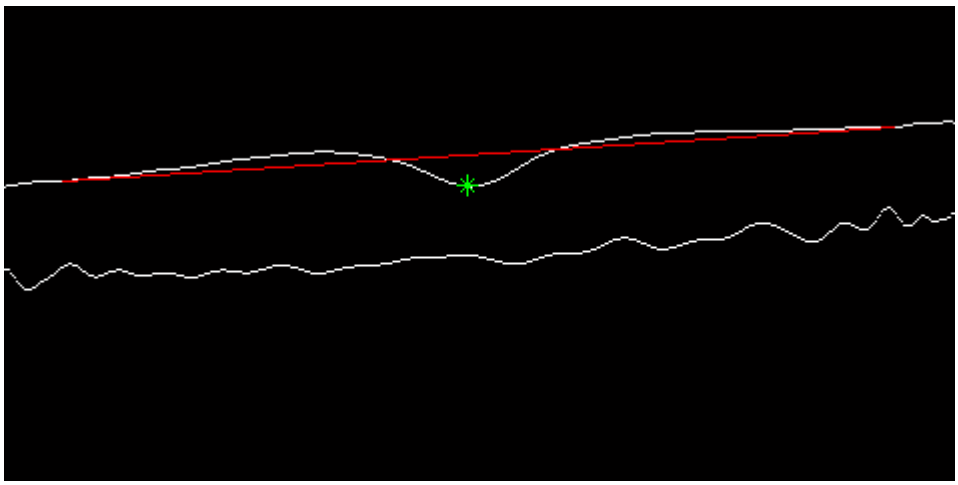

Figure 5.20: Fovea Marked OCT Image

Since Edema is the maximum Rise point in the ILM layer central region. For that, the distance between the image aligning straight line and ILM layer smoothed by polynomial fitting is calculated and the point giving maximum positive distance which is also greater than a certain threshold between the line and layer is marked as Edema point. Figure5.21 shows an OCT image marked with Fovea.

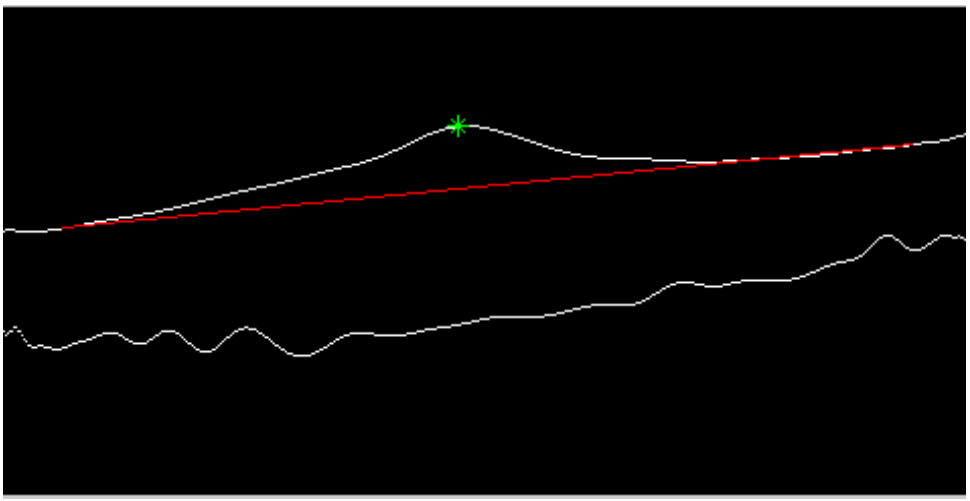

Figure 5.21: Edema Marked OCT Image

CHAPTER 6: Results

To make sure the performance of the Fovea and Macular Edema Detecting system, it is to be tested properly with all the possibilities of Input and Conditions. The more the testing of system is done, more the system is reliable.

6.1 Data Sets

Since there are no Datasets available for such system, that's why the OCT images used for the testing of Fovea localization are collected from AFIO. A local dataset of 500 images is collected for testing. The dataset contains images both with Fovea and without Fovea present in equal proportion. First the images are manually marked by some specialist and then these images are labeled by using this system. Finally the results of both images are compared and hence the performance and accuracy of system is calculated. Figure6.1 shows the sample dataset images. Left three images of Figure6.1 are ones with fovea present in them and Right three are the images having no fovea present.

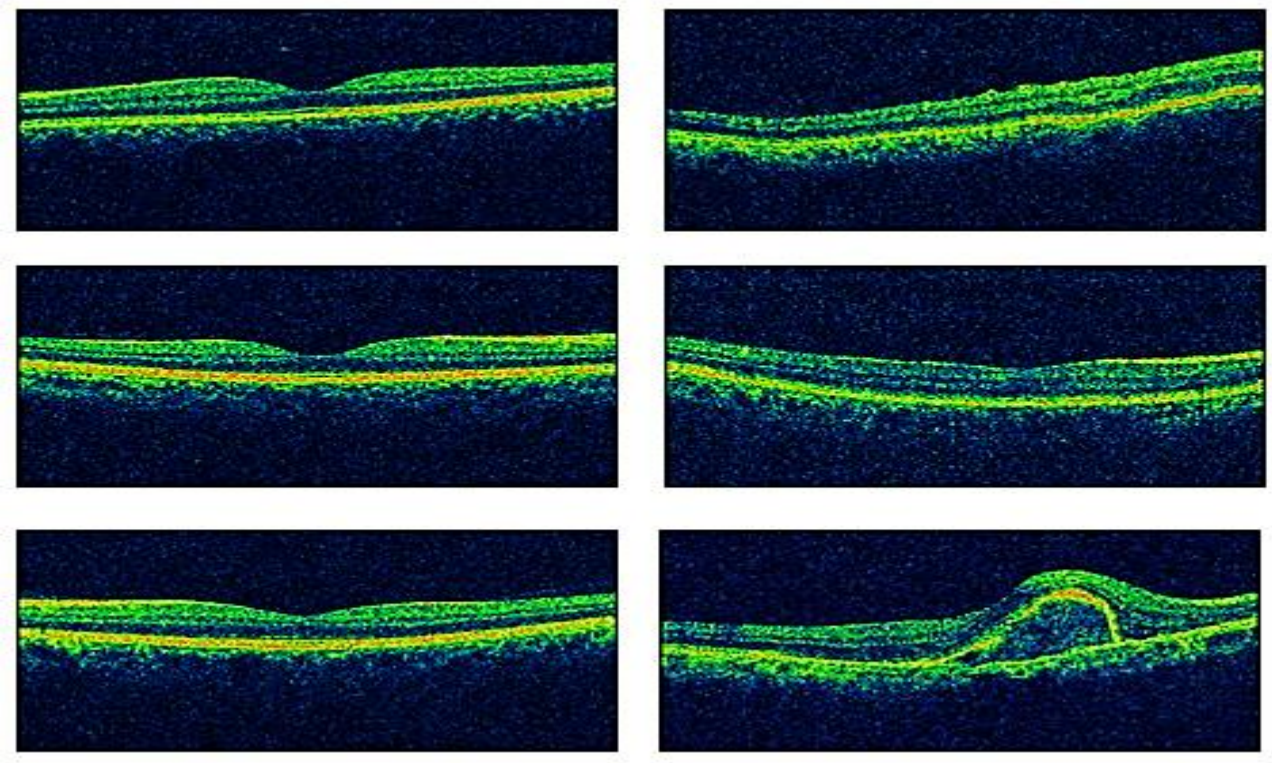

Figure 6.1: Sample Input OCT Images

Similarly a data set of 50 images has been collected from AFIO for macular Edema detection. Figure6.2 shows the sample data set images having Edema. Left three images of Figure6.2 are ones with No Edema present in them and Right three are the images having Edema present.

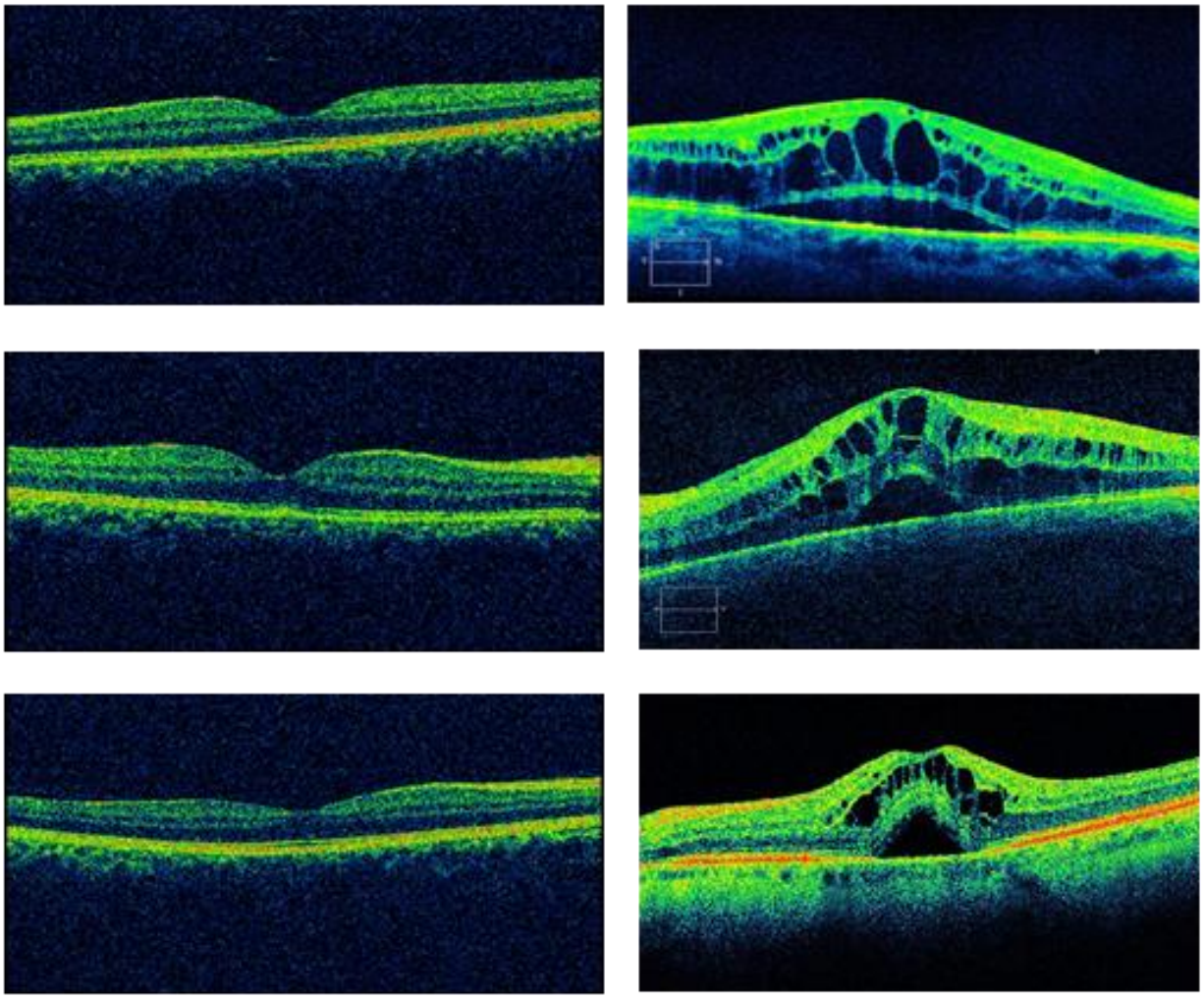

Figure 5: Macular Edema Data Set Images

6.1.1 Results

Out of total 500 images, there are 300 images in which fovea is present and 200 images does not have any fovea. This system first classifies the images into two categories i.e. Fovea and Non-Fovea. This system has correctly classified 275 images with Fovea and 185 images with non-fovea. This is 92% accurate. Figure6.3 shows step by step fovea localization. Figure6.4 shows some fovea labeled OCT images.

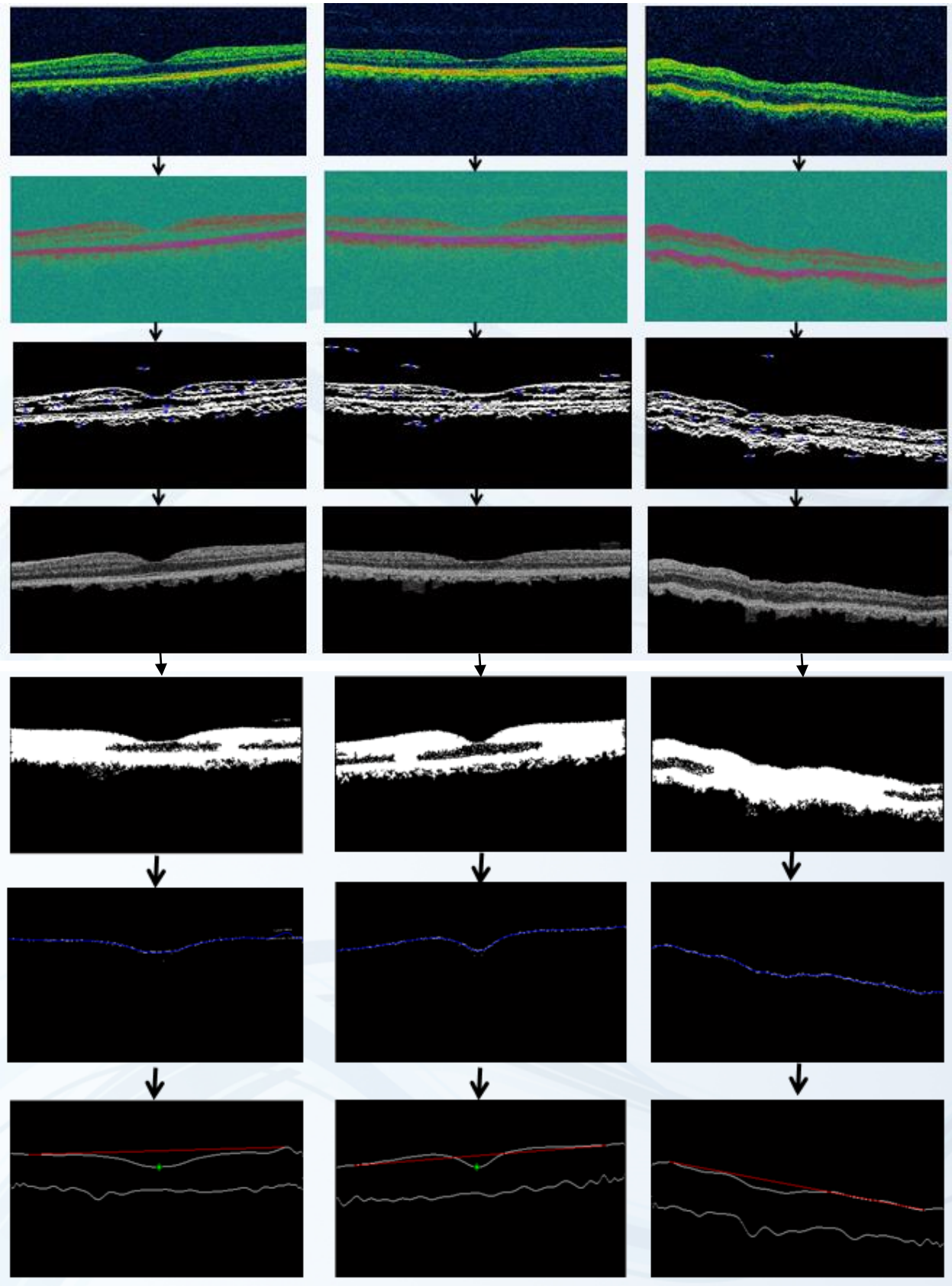

Figure 6.3: Step By Step Fovea Localization

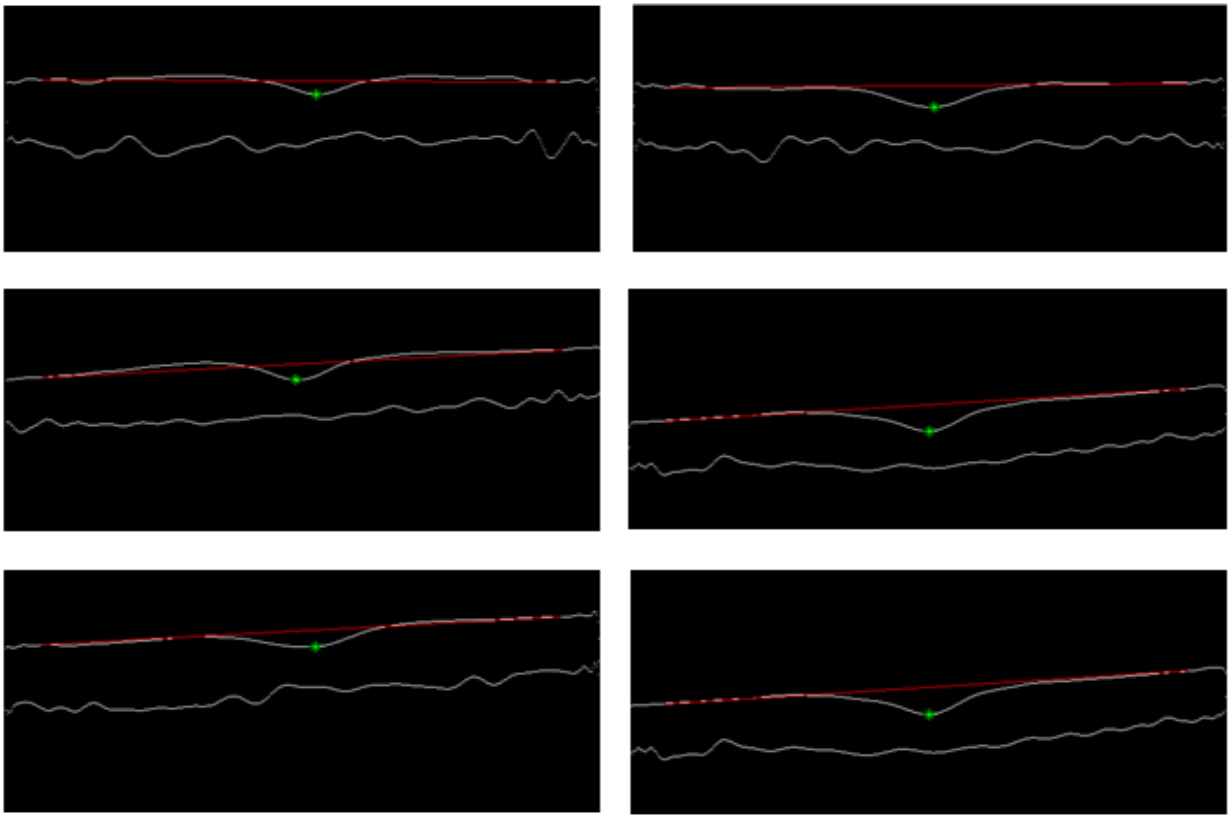

Figure 6: Fovea Localization Results

Similarly there are total 50 images of Edema dataset in which 15 images are normal and 35 are with Edema. This system correctly classifies 14 images normal and 28 images of Edema and hence the accuracy of system is 84%. Figure6.5 shows step by step identification of Edema. Figure6.6 shows some Edema labeled OCT images.

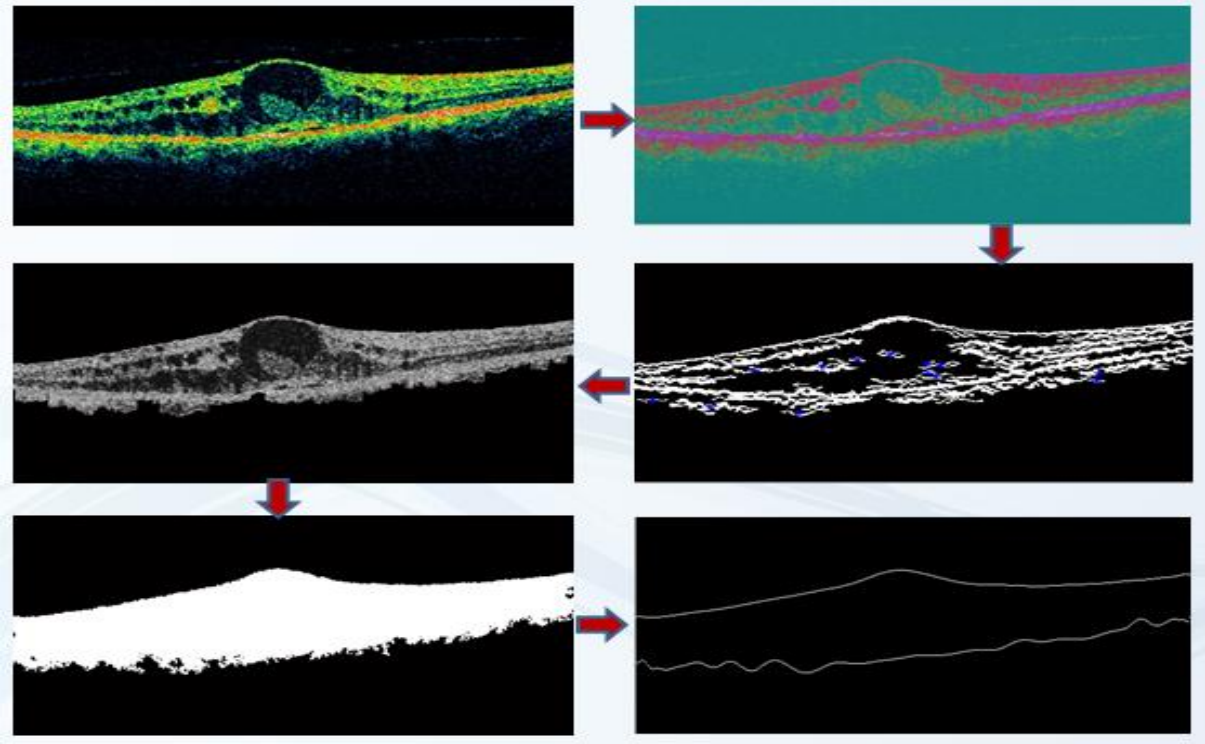

Figure 7: Step by Step Edema Detection

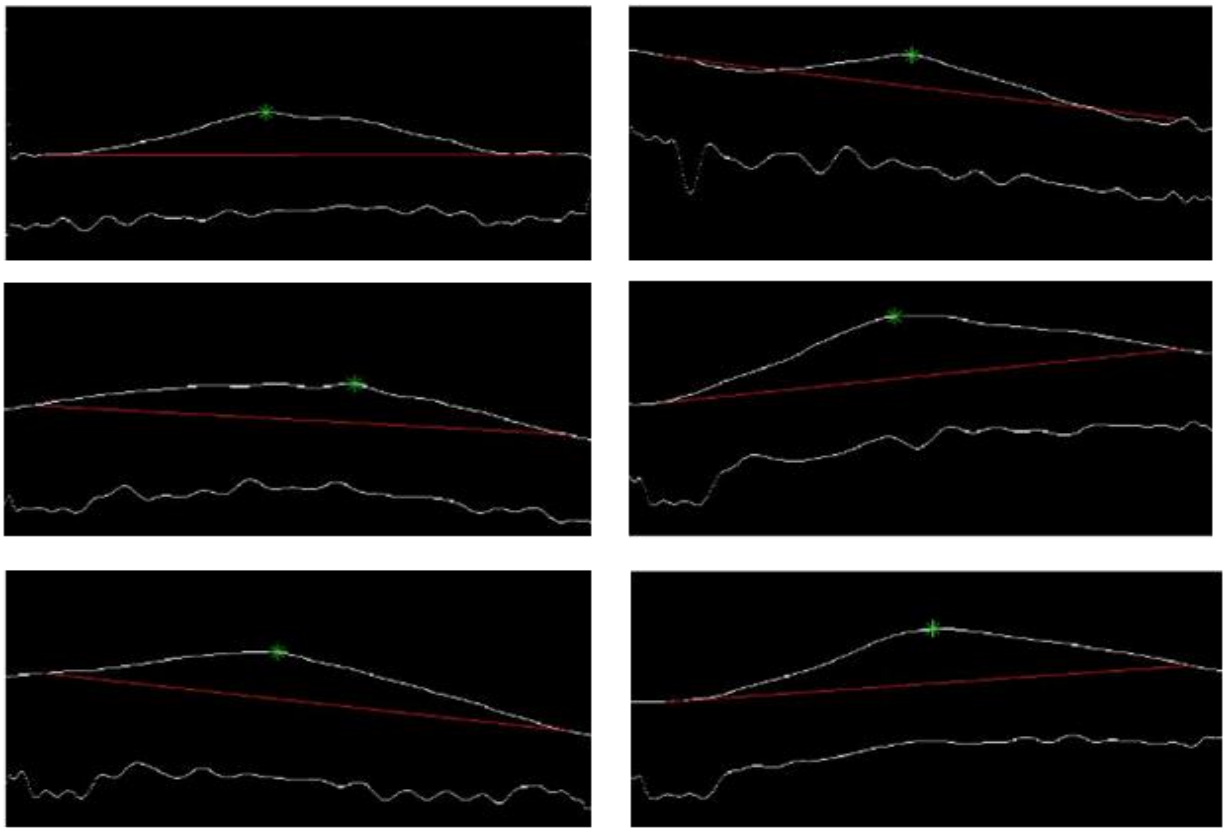

Figure 8: Edema Labeled OCT

Table6.1 and Table6.2 are showing the distribution of data in datasets. Also Table6.3 is showing results of overall system. For Macular edema detection, 42 out of 50 images have been classified correctly among Edema affected and non-affected images. Hence it gives an accuracy of 84% for macular edema detection.

Table 6.1: Data Distribution for Fovea Localization

TOTAL IMAGES	WITH FOVEA	WITHOUT FOVEA
500	300	200

Table 6.2: Data Distribution for Edema Detection

TOTAL IMAGES	NORMAL	WITH EDEMA
50	15	35

Table 2.3: Results Analysis

TYPE	SENSITIVITY	SPECIFICITY	ACCURACY
FOVEA DETECTION	0.925	0.91	92%
EDEMA DETECTION	0.93	0.8	84%

CHAPTER 7: Conclusion and Future Work

7.1 **Conclusion**

OCT imaging is a new technique for the detailed imaging of retina. Analysis of OCT images is helpful in detection of multiple diseases as the changes occurring in the retinal layers due to some disease can be easily observed with OCT image analysis. Fovea is the central point in retina which is responsible for central vision. Any abnormalities in it can cause the blurring of vision or loss of vision in severe cases. Also Macular Edema is the disease in which the sharp and pin-point vision gets affected. Since there is no work already done for the detection of such things using OCT imaging so the aim of this research is to device some algorithm for accurate localization of Fovea in OCT images which can further help in detection of multiple diseases like AMD, Macular Edema etc. Another aim is to develop a system which can automatically detect the presence of Macular Edema on the basis of Fovea region analysis. In this research a new technique is proposed for the localization of fovea. It works on the principle of line-layer distance calculation and the labeling of fovea at the maximum negative distance point. Before that the upper most retinal layer is successfully extracted out of OCT image which is the key element for further fovea localization processing. The extraction of ILM layer is done by using Active contour Based segmentation and polynomial Curve fitting techniques. Similarly the identification of Edema is done on the basis of rise in fovea region from a specific threshold. This system is further tested for a data set of 550 images and Fovea detection gives an accuracy of 92% and Edema detection gives an accuracy of 84%.

7.2 Contributions

Following contributions has been made through this research.

- Top retinal layer ILM has been extracted successfully.
- A new technique has been proposed for Fovea localization.
- An automated system has been developed for Macular Edema detection.
- The algorithm also works very well for some bad quality images.
- An accuracy of 92% has been achieved for the system developed for Fovea detection.
- An accuracy of 84% is achieved for Edema detection.

7.3 Future Work

7.3.1 Detection of Multiple Diseases

Since fovea has been successfully identified, now many other diseases other than Edema can also be identified by analysis of fovea region.

7.3.2 Grading OF Macular Edema

Macular Edema detection can be further graded into Cystoid Macular Edema(CME) and Diabetic Macular Edema(DME).

7.3.3 Working with 3D images

The algorithm can be further improved for the detection of fovea and edema in 3D OCT images for further improved and accurate results.

7.3.4 Mapping with Fundus Images

The reliability of the system can be further improved by mapping the OCT image results with Fundus images. The result given by OCT image can be cross checked by fundus image results which will increase the accuracy and reliability of results.

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