

2009

Digitech Ophthalmologist



Digitech Ophthalmologist

Improving patient care along with quality service and at the same time cutting costs might seem totally opposite goals, but that is exactly the promise of telemedicine. The term telemedicine covers an ever increasing number of techniques that put patients in touch with medical expertise over great distances. **Techlead Software Engineering Pvt. Ltd. India** is coming up with one stop solution for ophthalmologist, the **Digitech Ophthalmologist**.

Digitech Ophthalmologist

Digital ophthalmologist is a **software tool** developed by **Techlead software Engineering**. It has been developed with understanding of the ophthalmologist's concerns. This smart assistant to doctors will perform many of their routine and time consuming tasks in a much efficient way. Few examples are illustrated below.

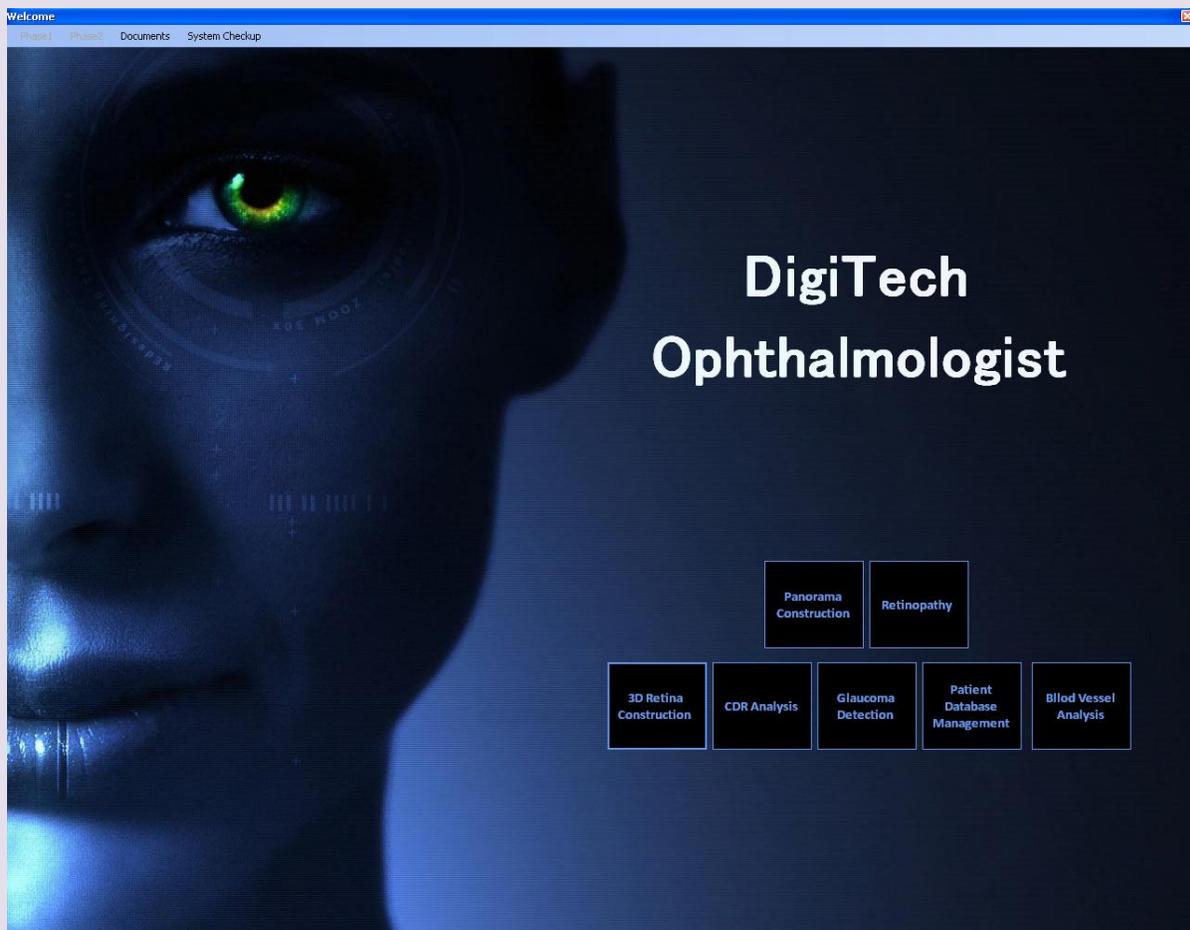


Figure 0.1 Digitech Ophthalmologist FrontPage

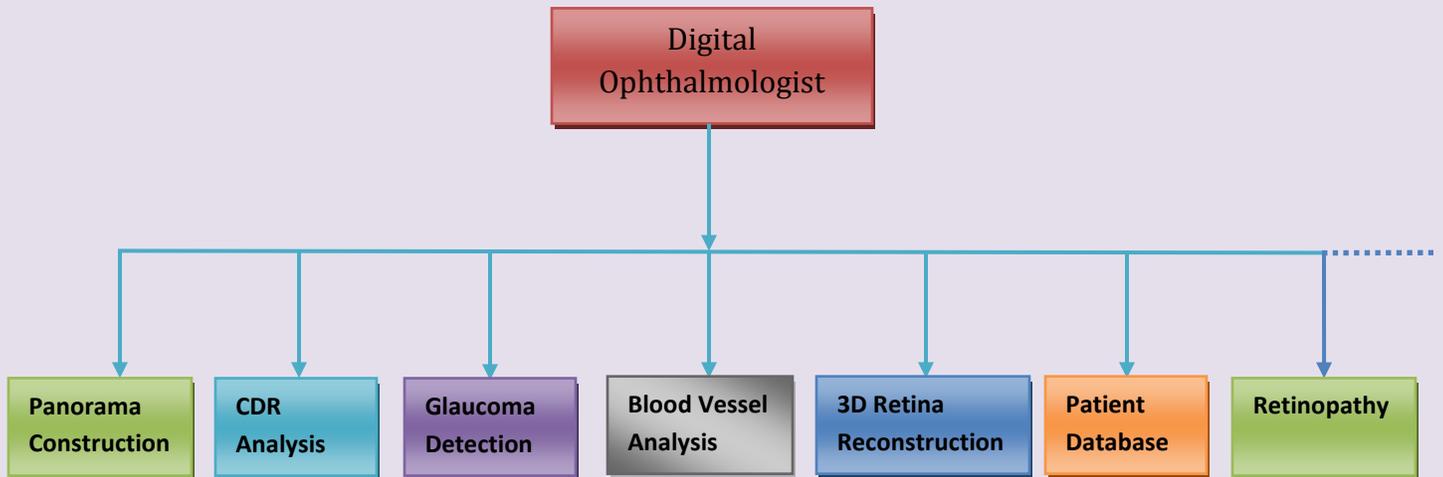


Figure 0.2 Block diagram of Digital Ophthalmologist feature list

Important Features of Digitech Ophthalmologist

- **Patient Database Management**

Once Images have been taken from a fundus camera, it is a difficult job to store the images in an organized manner. Doctors require a sophisticated tool to store the patient files in such a manner that it is easier to retrieve at any time. The parameters that should be concerned for designing the database are

- Store the data with respect to patient for track of his/ her disease history
- Access and search the database for a particular disease
- Allow multiple doctors to write their individual comments which will be stored in the same file.
- Create a portable file format in which it will be easy to share and email among various doctors for their opinion.

- **Distortion Correction:**

The retina image of the patient taken by the fundus camera contains distortion. This distortion occurs due to **Lens of the eye as well as lens of the camera**. This distortion can be minimized up to a certain level using **polynomial corrections on the radial axis**.

User can customize the values of the polynomial coefficients according to the camera lens used. Once the model is set, this distortion correction will automatically be used for all the images taken by the camera. Figure below shows the example of lens distortion effect on the image. The Image captured from camera is distorted. Distortion correction algorithm recovers the original image to the best possible extent.



Example of Lens distortion on an image, Left Image is original Right Image is distorted due to lens distortion

- **Panorama Image Construction**

The retina of the eye is curved. Therefore to compensate for the image distortion due to **curvature of the eye** and to obtain a **higher resolution image**, multiple retina images are taken. These images are taken at different but overlapping positions in order to get complete image of the retina without missing any details. This is necessary condition for accurate construction of the panorama Image.

- **Cup to Disc Ratio (CDR) Analysis**

Cup to disc ratio is a very important parameter especially in dis of glaucoma detection. Doctors can get a quantified single value as well as a peripheral (360°) CDR in form of a graph. This algorithm involves following steps:

1. Accurate Disc contour detection
2. Accurate Cup contour detection
3. Measuring CDR in 360° around the optic disc centre and generating reports

- **Retina 3D Reconstruction**

Data visualization in 3D is a dream come true for doctors. This technology has been very helpful in radiology so far. We have come up with the similar solution for ophthalmologist. We have developed novel 3D retina image reconstruction algorithm on the basis of stereo vision. This 3D visualization will be of a great help in case of cup and disc shape analysis.

- **Blood Vessel Analysis**

Blood vessels have lot of clinical significance when it comes to diagnosis of disease. Accurate measurements of blood vessels can provide doctors a great deal of assistance for diagnosing a disease. Digitech Ophthalmologist assists doctors in the following calculations

- AV Ratio
- ALR Ratio (Light Reflex)
- AV classification
- Vessel Tree formation

For blood vessel analysis, Techlead has invented a proprietary algorithm '**Strokes**'.

- **Glaucoma Detection**

Glaucoma refers to a group of diseases that affect the optic nerve. This is caused by the variations in intraocular pressure. Glaucoma detection algorithm is a screening algorithm which basically decides if there is any possibility of glaucoma in the input image. The algorithm has been tuned for least false negative.

- **Retinopathy**

Retinopathy is a general term that refers to some form of non-inflammatory damage to the retina of the eye. Under retinopathy following algorithms have been developed

- Image Screening – Deciding if the input image is normal or abnormal
- Smart Diseased Area Locator – Extracts the contours of possibly diseased areas
- Disease Tracker – keeps track of diseased area changes in chronicle reading of patients
- **Training**- this is a feature with which doctor can train the software assistant. Doctor can train for extracting the diseased areas; detecting normal and abnormal Images and almost all the features that doctor wants its assistant to follow. The User Interface for training has been designed in a simple manner making it easy to use.

This software assistant can also help doctors for preliminary diagnosis and storing the input images in an organized manner.

For the purpose of training, established sophisticated Artificial Intelligence algorithms have been used. Following is the list of methods used

1. **Fuzzy classifiers**
2. **Neural networks.**
3. **State Machines**

Conclusion

Digitech Ophthalmologist is a

- Software tool to help ophthalmologist
- It works on the given retina Images and alleviates the painstaking and routine tasks of ophthalmologist
- Also helps in screening, preliminary detection of disease and organizing the database.

Digital Ophthalmologist is NOT a

- Hardware to capture retina Images (user requires a separate fundus camera)
- It cannot give suggestions to doctors unless trained properly. The training process works continuously in the background. It starts giving opinions when they start matching with the doctor's diagnosis for substantial cases.

In the following subsections, each of the above listed features is explained in detail.

1. Panorama Construction

The retina of the eye is curved. Therefore to compensate for the image distortion due to curvature of the retina and also to obtain a higher resolution image, generally multiple retina images are taken. Figure below shows 7 different positions where individual retina images are taken. These images need to be overlapping in order to get complete image of the retina without missing any details. Panorama Construction is a process of combining all these individual image pieces to form a complete image

Challenging task

- Images are distorted due to the curvature of lens of eye as well as the camera
- Therefore manually stitching individual images is a tedious and time consuming job
- Panorama Construction utility from the Digital Ophthalmologist can do this job in no time.
- The algorithm removes the effect of distortion adequately and also takes care of small mismatches (due to distortion) to generate a complete panorama Image.

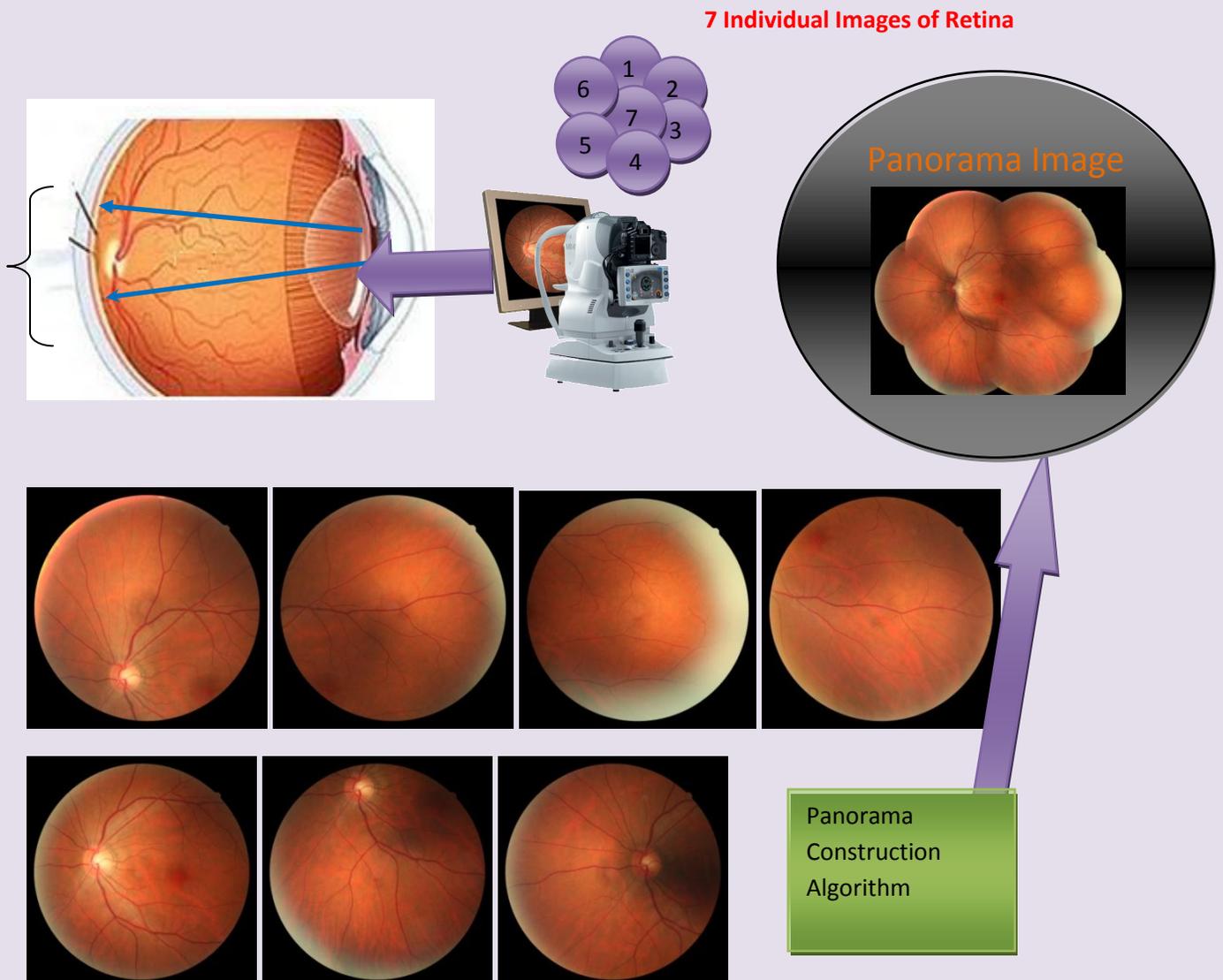


Figure 1.2 Overall Picture of Panorama Construction. Small images 1- 7 shows input images taken at different position (shown in the purple circle near the fundus camera). These Images are subjected as input to **Panorama Construction algorithm** and the resultant stitched image is as shown in top right corner under the heading **Panorama Image**

This panorama Construction Algorithm has been tested with more than 100 datasets. The accuracy has been tested thoroughly. The algorithm is also time efficient (It requires 30-35 seconds for stitching 7 images. Each image is of size 9MPixels). The variation of the execution time of the algorithm depends on vessels in the particular image. Testing is done with a P4 core 2 duo processor with 2GB RAM.

2. CDR - Cup to Disc Ratio (CDR) Analysis

Introduction and Significance

Cup to Disc Ratio is a ratio of surface area occupied by cup divided by surface area of disc. The optic disc is the anatomical location of the eye where blood vessels and optic nerves enter in retina. Optic disc is usually flat while the optic cup which is located inside the optic disc has certain amount of cup like features.

Sometimes due to the intra ocular pressure, the cup area enlarges until it occupies most of the disc area. Therefore the cup to disc ratio is a measurement for quantification of the progress of glaucoma or of the certain pathology causing changes in ocular pressure. For the purpose of accurate CDR, the boundaries of the cup and disc are needed to be calculated precisely.

Current CDR Method: Manual

1. The doctor uses the color image for diagnosis. As shown in the figure 1.1, the optic cup boundary is not clearly visible. The minute details may not be apparent to the human eye in this case which might be seen by the algorithm.
2. The most standard model of colored images is RGB but there are many other color models in which a particular aspect of image can be enhanced. Contour detection algorithm uses adaptive preprocessing using various color models (e.g. CMYK, YIQ) depending on the input image statistics. This operation enhances the boundaries in such a way that contour detection becomes easier
3. Its time consuming and tedious to manually go through all the images and mark with hand.
4. Manual error of drawing also comes into picture here. Example image below shows the difference.
5. Repeatability of results cannot be guaranteed using manual marking

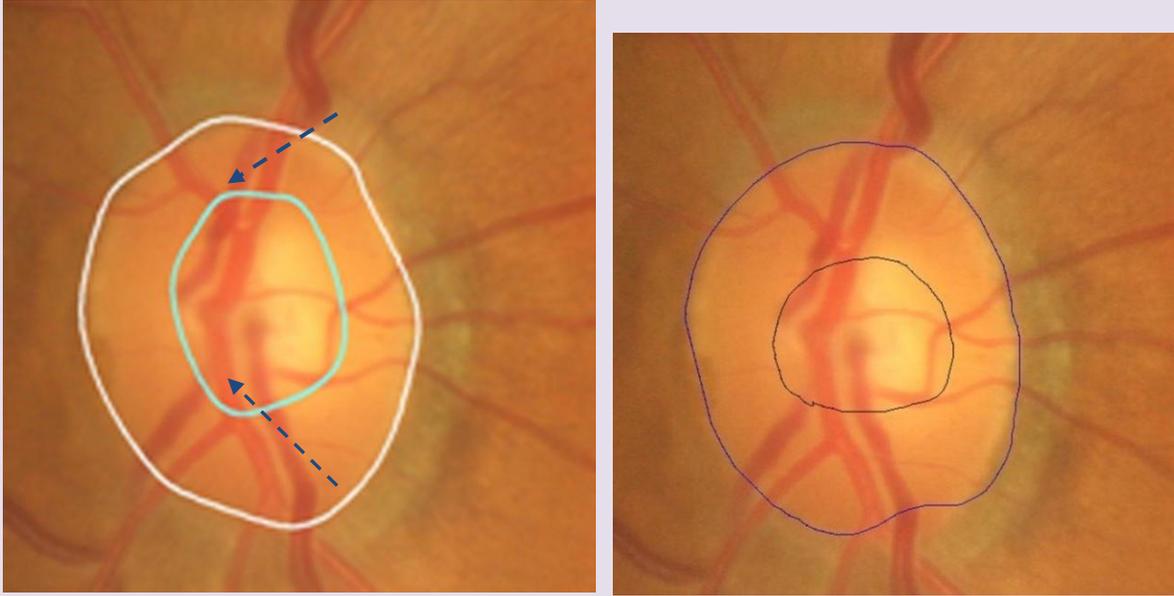


Figure 2.1 Example of manual and Automatic Marking of Optic Disc and Cup boundaries.

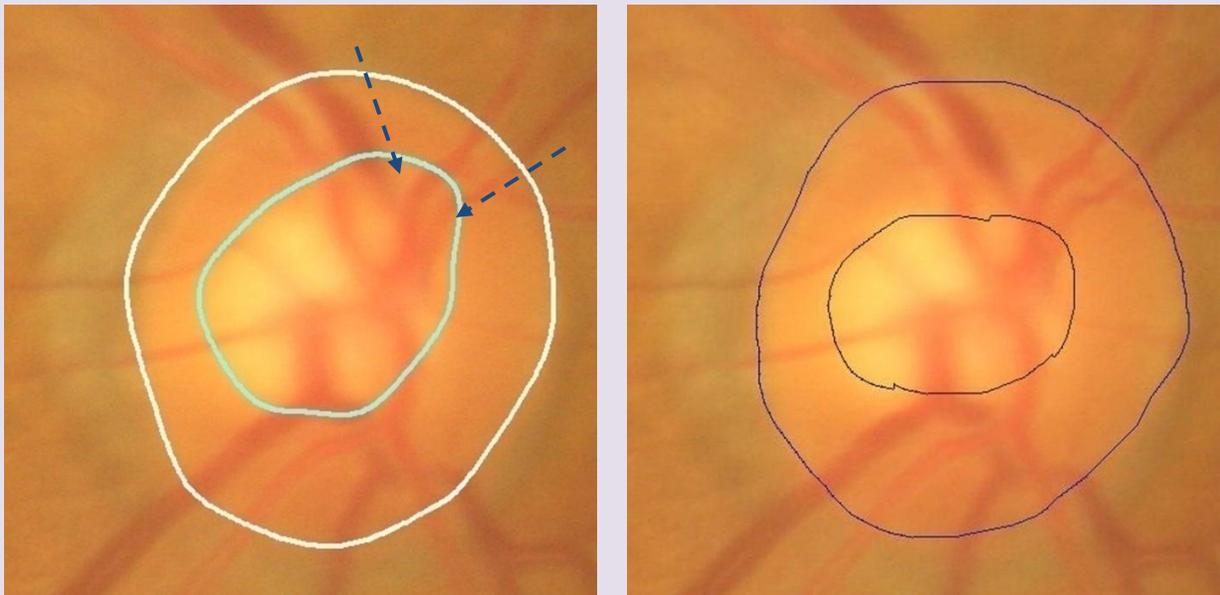


Figure 2.2 Another example of automatic detection to the manual detection,

Figure Explanation

Left Image is manually marked cup and disc boundaries. Right Image, automatic boundary detection. The Arrows in the left images shows the ambiguity of cup presence. Optic disc has been marked properly by manual as well as automatic methods.

Algorithm: Active Contours

The algorithm which has been used for correcting the contour is **snake**, also known as Active contours. This algorithm is a gradient based intelligent feature extraction tool. It can be imagined as a rubber band which is stretched around the boundary according to the image gradient at that point. Once initialized the contour automatically moves along the GVF (Gradient Vector Flow) defined at the location. Snake algorithm works best in accuracy as well as in time when the initial contour is put close to that of the actual contour.

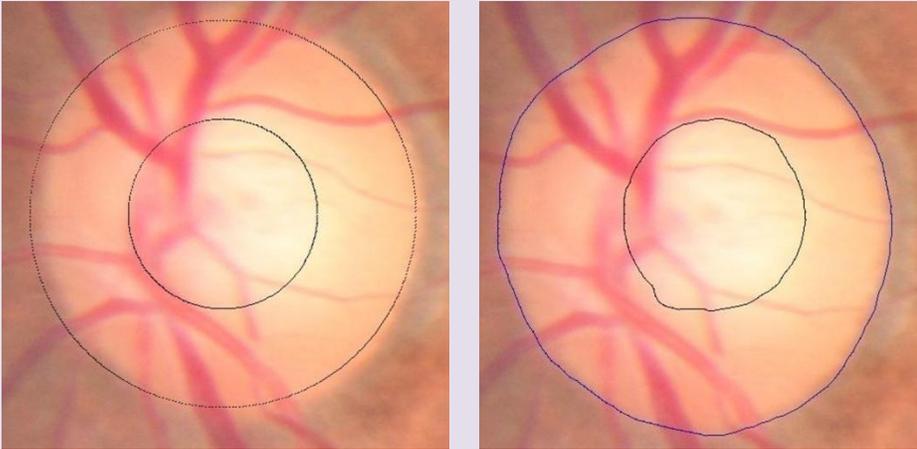


Figure 2.3 Initial (contour supplied) and final contour (after snake operation is complete).

Figure illustrates the output of snake algorithm on an optic disc image where the initial contour is placed near the actual boundary. Left figure shows the initial contour placed which is input to the snake algorithm while right image shows the contour after approximately 50 iterations.

Normal CDR is in the range of 0.3 that means the cup takes around 30% area in the disc. If this ratio exceeds means that intraocular pressure is increasing and the cup is growing. This can be considered as a reason to suspect glaucoma.

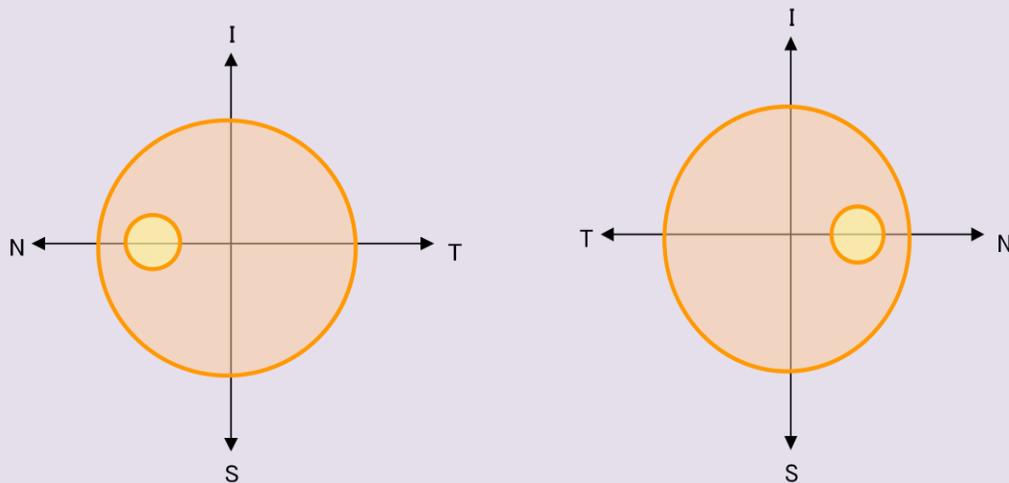


Figure 2.4 Left Eye Data

Right Eye Data

Figure 1.4 shows the left and right eye annotations used for measuring the cup to disc ratio. N denotes the nasal side while T is the ear side. I denotes the head while S denotes the downwards region. Figure below shows the detected cup and disc as well as the CDR along the periphery of the eye for complete 360°.

Example of such a comparison is given in the figure below.

1. Disc Contour
2. Cup Contour
3. Cup to disc ratio
4. Difference between Cup to Disc Ratio for two datasets on different dates

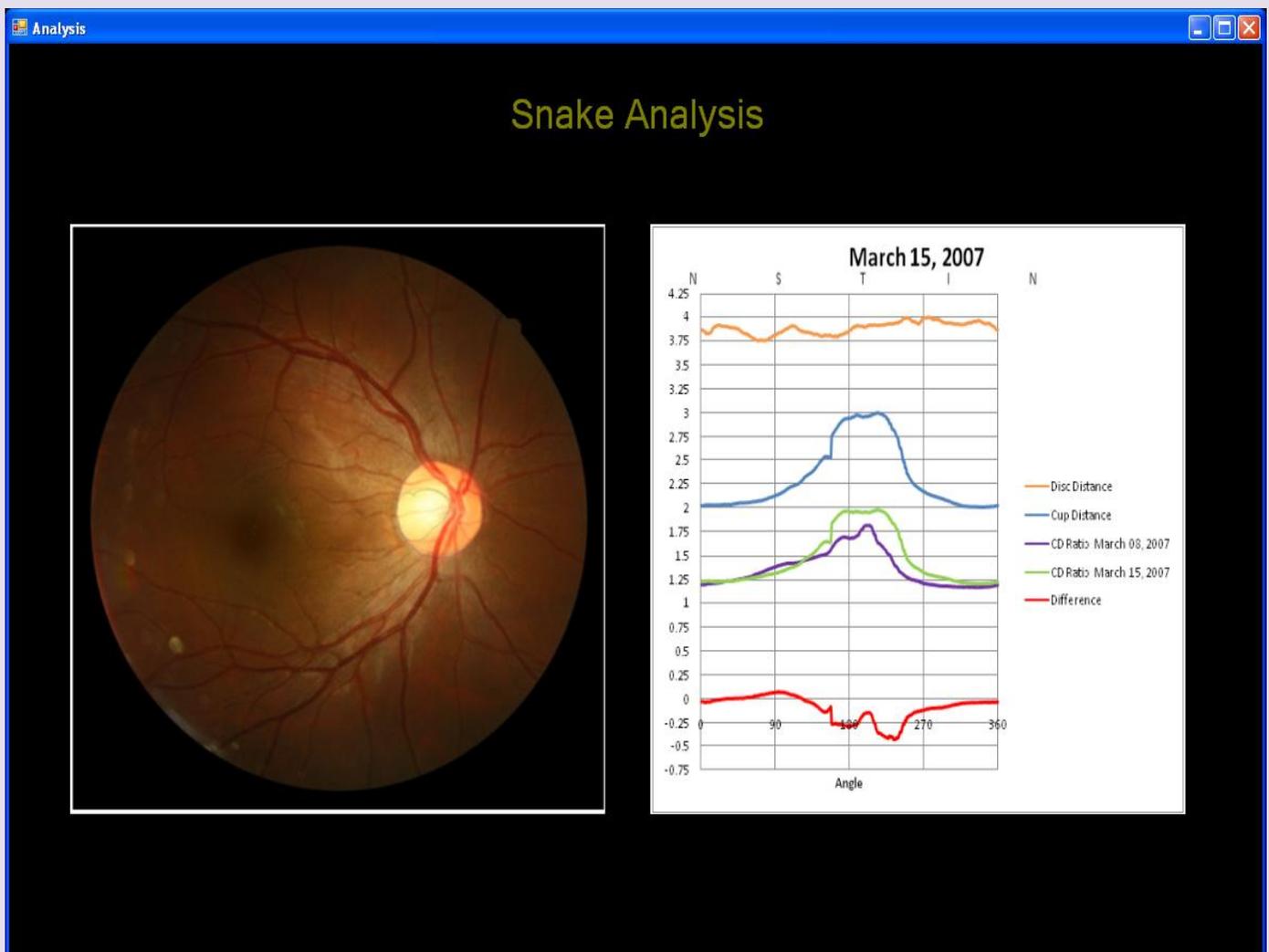


Figure 2.5 CDR reports using Snake Analysis

3. Glaucoma Detection Tool

Glaucoma refers to a group of diseases that affect the optic nerve. This is caused by the intraocular pressure. If not treated in early stages can result in the loss of vision which can progress to blindness. It is caused gradually and over a long period of time without warning which is why it should be detected early with regular checkups.

Physiological Appearance

- Glaucoma is characterized by a **Fan-like beam Pattern** in the region near Optic Disc.
- **Extension of Optic Cup** almost to the Optic Disc boundary is observed along with this Fan-like pattern.
- **NFL** (Nerve Fiber layer) has a **striated appearance radiating from** the Optic Disc.
- The **Fibers** travel in an **organized pattern** (Parabolic Path), superior and inferior to the Optic Disc.

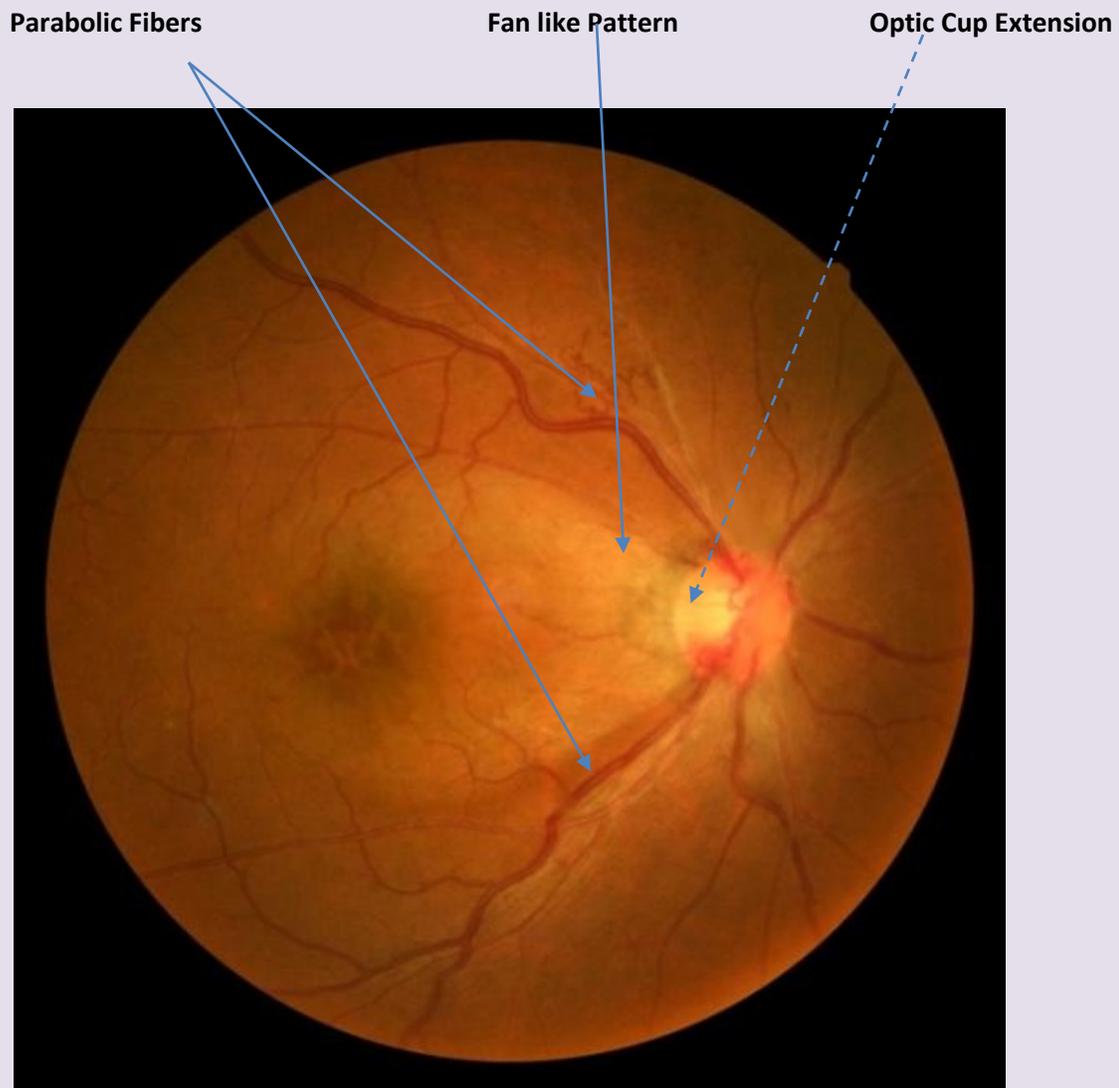


Figure 1.1 Retina Image with possible Glaucoma

Algorithms for Glaucoma Detection

- For a greater accuracy of identification of the presence of Glaucoma and NFL (Nerve Fiber layer), three methods have been devised.
 - Fourier Series Descriptors
 - Median Radial Transform
 - Hough Transform
- These Algorithms calculate a possibility of Glaucoma which can effectively help Doctors to identify if the patient is having glaucoma. (Help only in Screening)

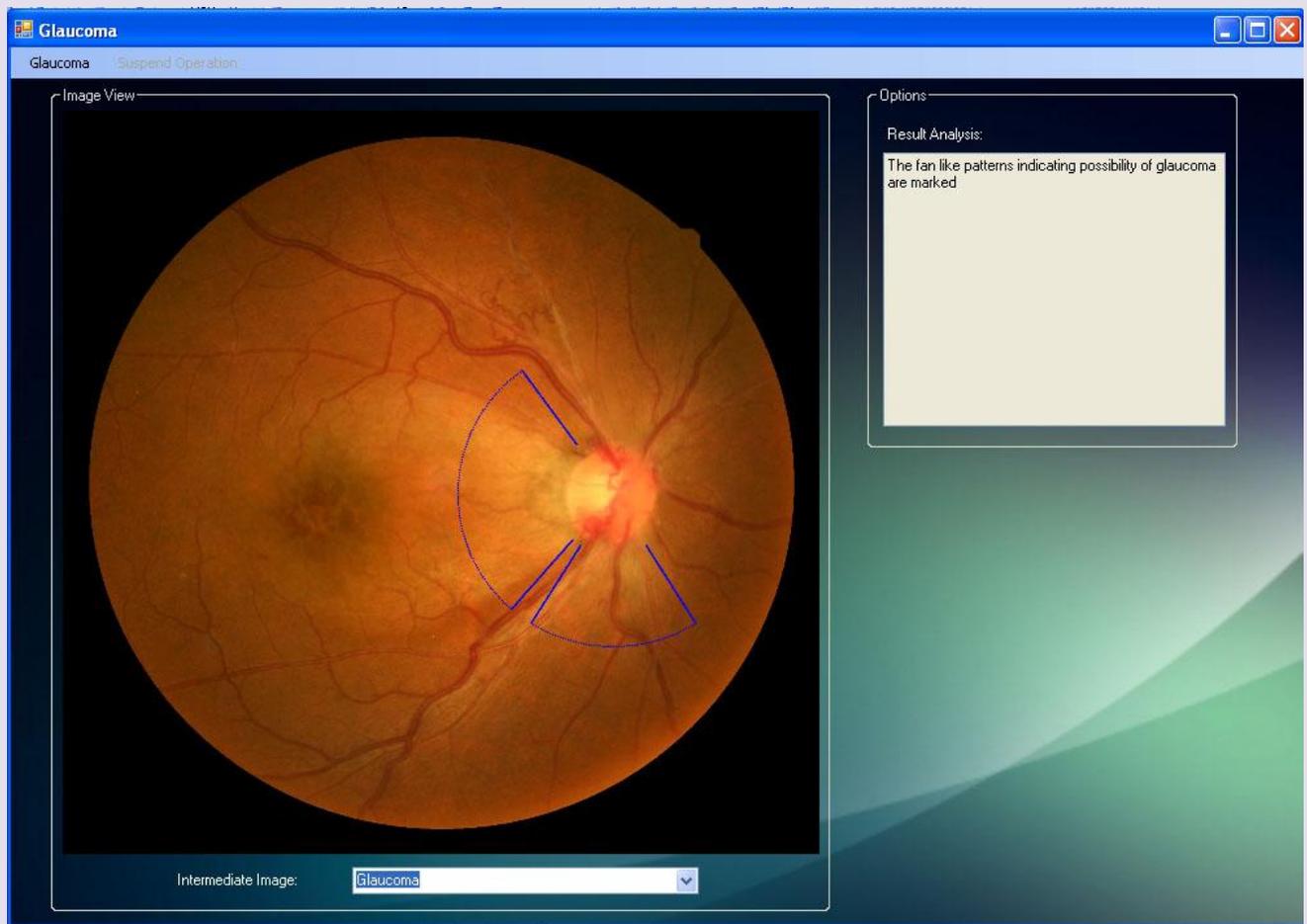


Figure 1.2 Detection of Glaucoma, GUI shows the detected glaucoma

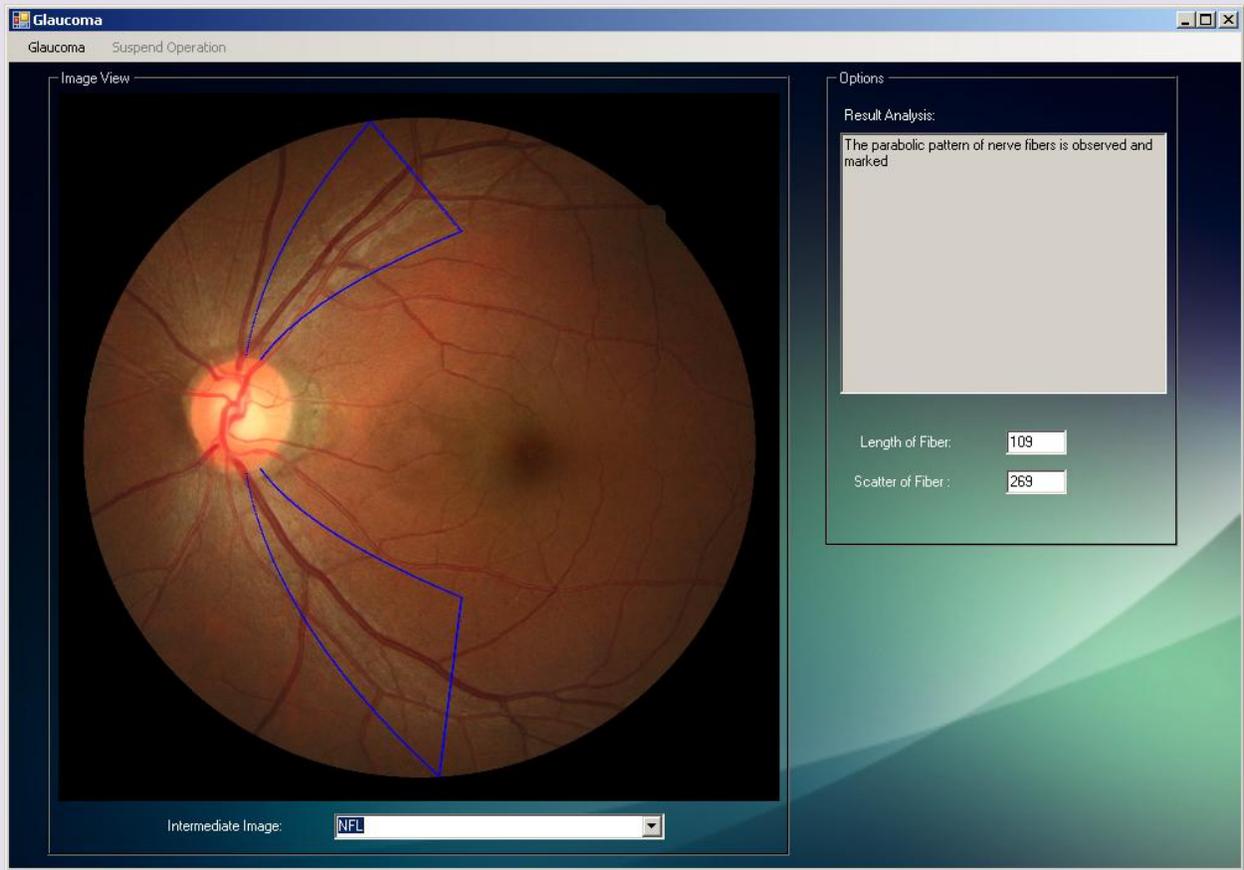


Figure 1.3 GUI showing the NFL detection and the calculated parameters, length and scatter

4. Blood Vessel Analysis

Vessel tracing algorithm is the backbone of all other algorithms. By and large accuracy of all the other algorithms mostly depends on accuracy of vessel tracing.

Blood vessels have lot of clinical significance when it comes to diagnosis of disease. Accurate measurements of blood vessels can provide doctors a great deal of assistance for prediction of diseases. Following are a few parameters which are explained along with snippets of clinical significance.

Significance of AV ratio:

Generalized arteriolar narrowing is one of the retinal changes influenced by systemic hypertension. The ratio of retinal arteriolar to venular diameters is often used as a marker of generalized arteriolar narrowing. Normally this ratio is measured before third bifurcation (as in a vessel tree) of the vessel and its value is supposed to be between 0.6 – 0.8. Due to a series of diseases, this ratio gets affected.

1. Diabetes: veins are abnormally wide.
2. Hypertension: Arteries are narrowed down.
3. Optic atrophy: all vessels may get attenuated or in some cases arteries may become abnormally narrow

There are a number of conditions that can alter the normal A/V ratio, but one must pay attention to which of the two have changed. Are the arteries abnormally narrow or are the veins abnormally wide? This will help the diagnostic process.

Significance of ALR: Arteriolar Light Reflex

The (ALR) is the ratio of the width of light being reflected off the surface of the artery to the overall width of that artery. As the walls of the artery are thick, less light is allowed to pass through the artery, more is reflected back. Due to this reason the arteriolar light reflex becomes a good measure of **arteriosclerosis and atherosclerosis**.

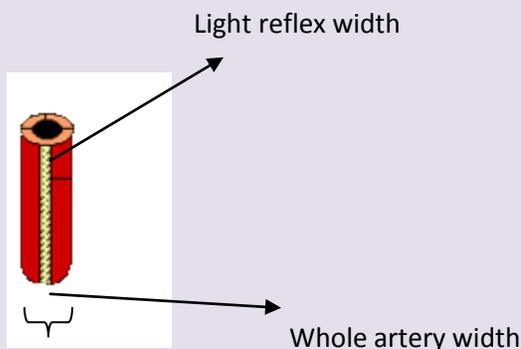


Figure 4.1 Illustration diagram for Arteriolar Light Reflex AOL

Normal ALR is in the range of 0.2 to 0.33. If this ratio exceeds this figure, alert can be sent to doctor. This factor can also be used to check overall health of the eye.

At Techlead, we have invented an entirely nonconventional approach for the extraction of vessels. This **strokes** algorithm is capable of extraction of vessel data even from images where vessels are not clearly seen to the normal human eye. This algorithm returns a strokes image of the input image.

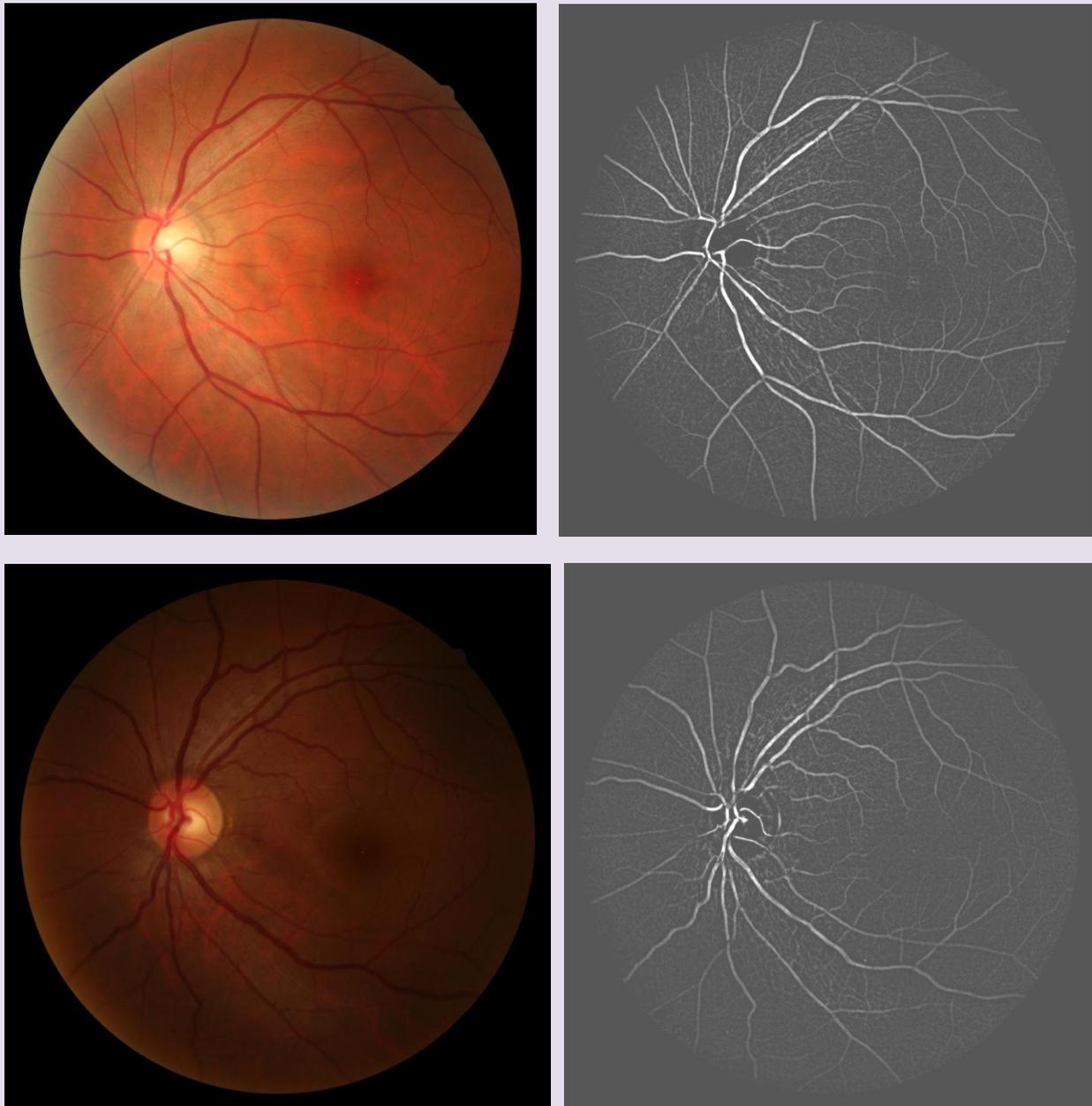


Figure 4.2 Output of Vessel Strokes Algorithm, Detecting vessels from the even worst images

Once the **storkes** Image is obtained, adaptive vessel tracing algorithm is applied on the stroke image. This tracing algorithm returns

- *Vessel Tracing*
- *Vessel Boundary*
- *Vessel Tree Formation*
- *Vessel Classification (Arteries and Veins)*
- *Calculates the AV ratio at second bifurcation for parallel vessels*
- *Calculates the ALR ratio.*

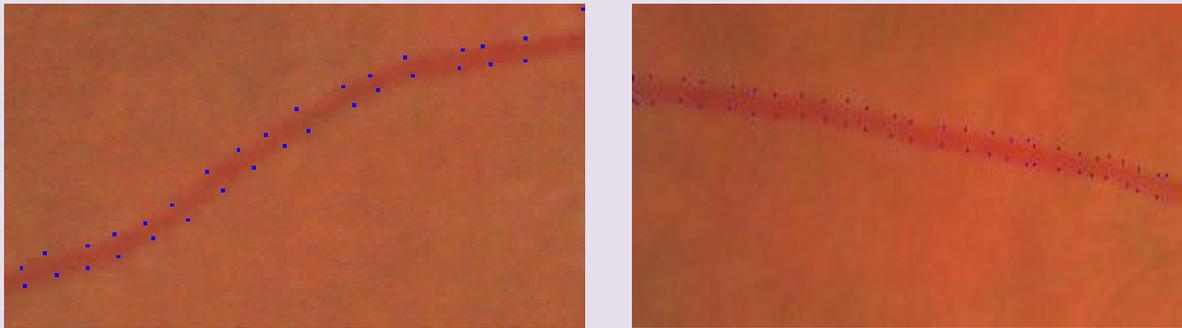


Figure 4.3 Detected Vessel Edges, Accuracy of edges is important for the accurate estimate of Blood vessel parameters.

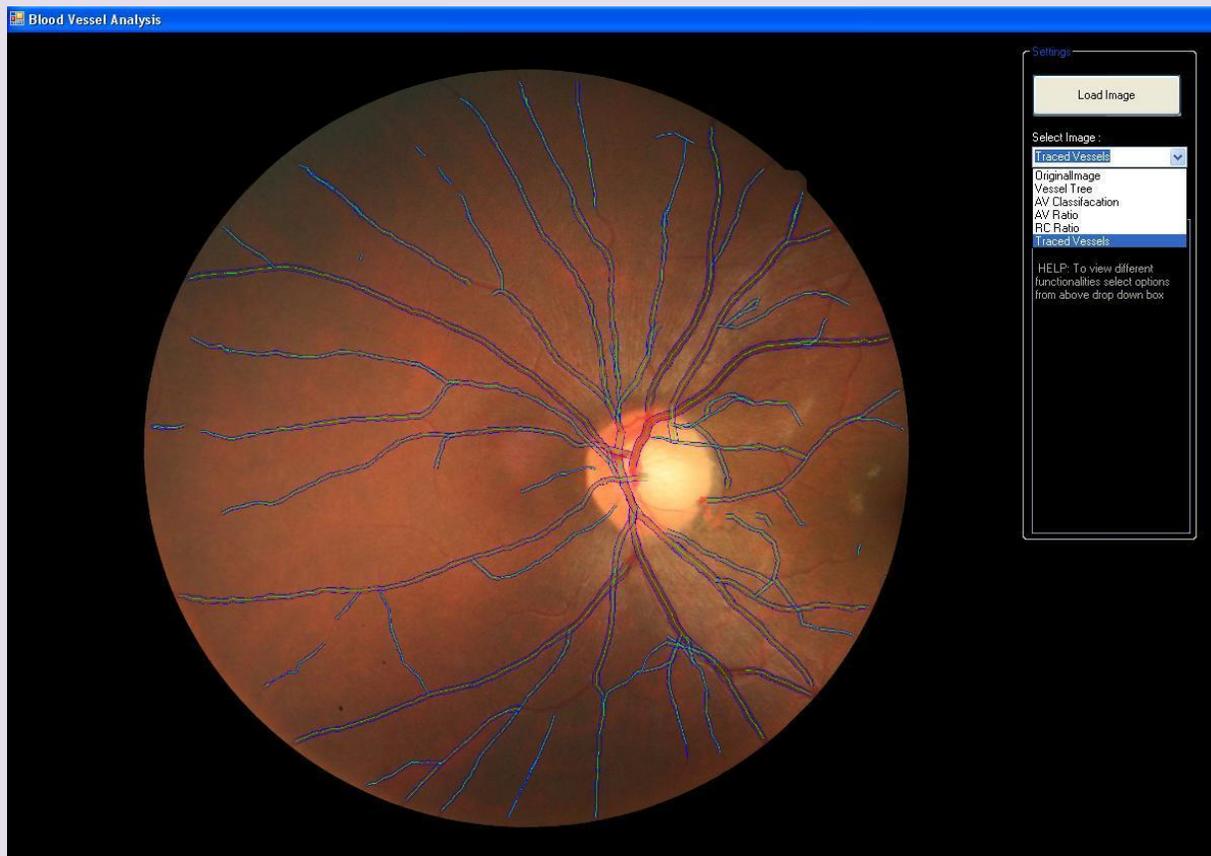


Figure 4.4 GUI showing traced vessels, same UI shows ALR ratio, AV Ratio, Vessel Tree etc. Select option from the list box.

5. Retina 3D Reconstruction

Introduction

3D analysis of patient's data is a very useful and important tool in many of the biomedical domains especially used in Radiology. It will be a great help to the ophthalmologist if the data can be visualized in 3d domain. This will help in better visualization of the anatomy especially in case of surgery. There are 2 major steps involved with the 3d visualization of the object

- Generation of 3D data
- Visualization of 3D data

Proper 3D data creation is of utmost importance, even more important than that of the visualization tool.

Generation of 3D data: Stereo vision

In general, to generate 3D information from 2D images (the topic being presented here), one needs a pair of image of the same object taken at the same instance (especially for moving objects). It is possible to extract the information about the 3rd dimension (Depth) by simultaneous analysis of these 2 images. This technique of generating the depth information from a pair of stereo images is called 'Stereo Imaging' (This is the same concept, by which all of us are able to see the world in 3D when we have two 2D retina images as input to the brain).

The 2 images here need to be taken from a pair of cameras with their lens arranged in parallel. An example of such a case is being presented here:



Figure 5.1 Left image

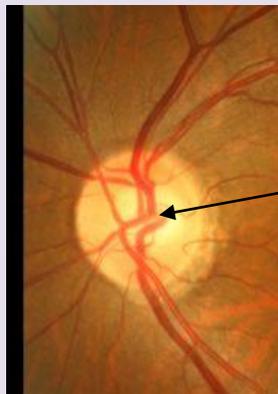


Figure 5.2 Right image

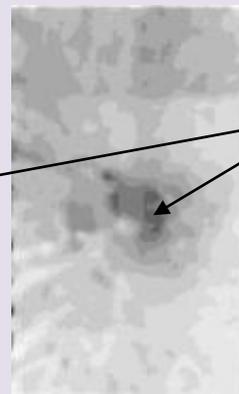


Figure 5.3 Depth image

Dark region indicates region away from us and the bright area shows the regions nearer to us.

So, in all this image indicates that the central area is depressed compared to the surrounding

An algorithm has been developed which takes as input the pair of images presented above and generated the third image as output. The third image depicts the depth information in terms of

intensity. In general this algorithm is called as stereo algorithm. The stereo algorithm that has been developed at Techlead works best for images taken by a parallel camera pair.

However, many times due to unavailability of the required setup, the images may be captured by a single camera, by moving it at two different positions. The algorithm has been designed robust enough to take care of the minor alignment issues that may arise as a result of camera or object movement between the two images capture.

3D viewer:

This is a tool developed for the 3D visualization of the structures. The prerequisite for this viewer is

1. Image or texture of the object which needs to be seen in 3d
2. The depth map which holds the information about the depth dimension of the texture or image.
(Similar to the depth images explained in the figure 3)

The tool is user interactive; the user can tilt, pan and rotate the 3D structures to view it from different angles. Also the data can be visualized as texture as shown in left image and also as wire mesh as shown in right image. The screenshots of the 3D view attached above are depicting the Depth image (Fig. 5.3) presented in the previous section.

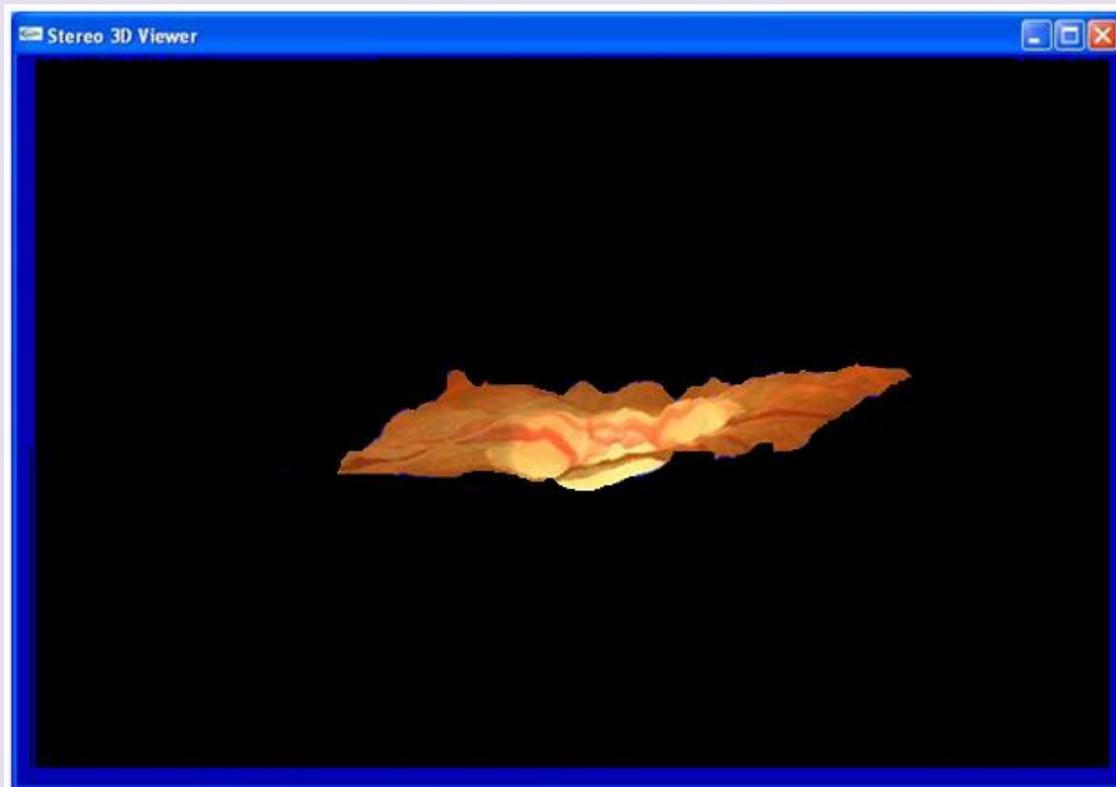


Figure 5.4 Texture of Image view

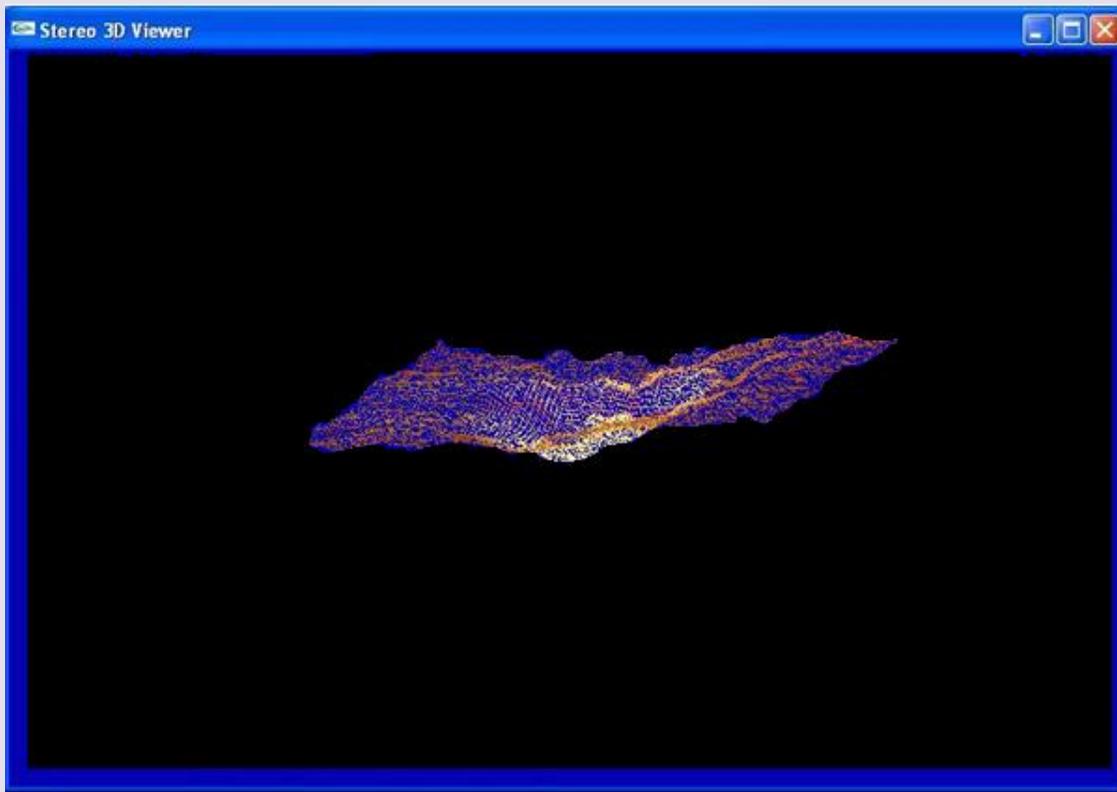


Figure 5.5 Wireframe views of the same 3D image seen from same view angle

Smart Features of Digitech Ophthalmologist: 3D Reconstruction Algorithm

1. Generates 3D information in the form of a text file as well as an image.
2. Works best for images taken from a Stereo parallel camera, but the algorithm is robust enough to work on images taken from a single camera parallel imaging.
3. Automatic Y shift correction.
4. Automatic Disparity range identification.
5. Automatic cropping of the Area of Interest (Optic disc and the nearby surrounding region).
6. Automatic rotation correction.
7. Ability to identify the Left and Right images if input is passed out of order.
8. Facility to manually change some of the settings and reapply the algorithm on the same input.
9. Facility to fine tune the parameters (Intelligent defaults already stored).
10. Facility to selectively enable or disable certain features of the algorithm.
11. View the result in an interactive 3D viewer.

Application of the 3D viewer

- Cup to Disc Ratio validation,
- Examining the cup structure
- Also used as a debugging tool for development where intensities of vessels can be viewed in 3d which gives better idea of vessel the structure (screenshot shown in following figure 5.6). With this application, any random pattern around the vessel can be seen.

Advantages

- The most important advantage of the 3D viewer algorithm is that it provides the actual anatomical information noninvasively i.e. not causing any surgical trouble to the patient. Doctors will be able to diagnose better as the information is being provided in the best possible fashion.
- Easy to use with intuitive features
- Detailed viewing options such as panning, tilting, zooming in all directions is possible in order to give the closest look at the image feature.

6. Retinopathy

Retinopathy is a general term that refers to some form of non-inflammatory damage to the retina of the eye. The reasons for this condition are several including diabetic condition. Persistence of this clinical condition can result in loss of vision.

The retinal damage can be a result of many pathological conditions such as bleeding from ruptured blood vessels, swelling in the optic nerve, particularly at the area that controls fine vision (macula). Under digital retinopathy, all these symptoms can be perceived as abnormally colored regions in the retinal images.

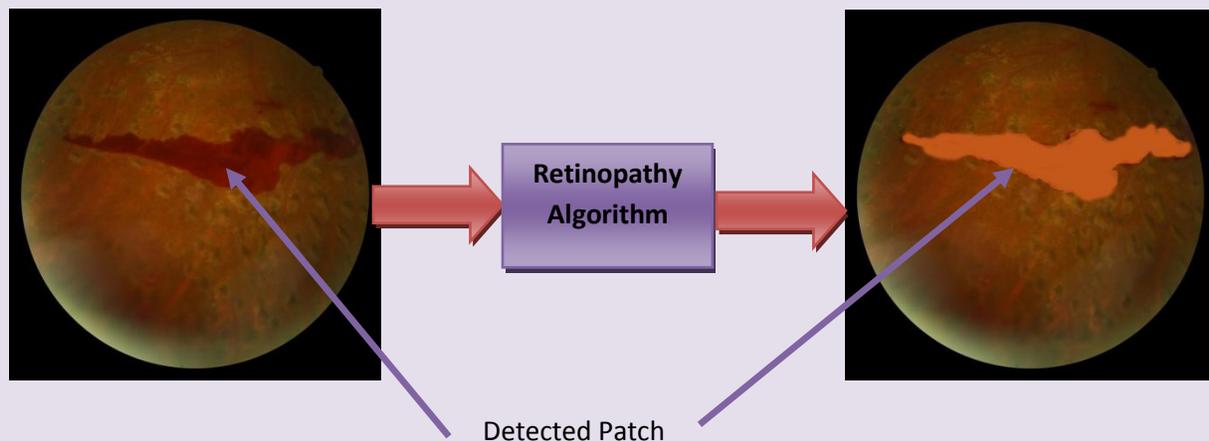


Figure 6.1 Example of Retinopathy

Salient Features

Smart Assistance to doctors

This tool is like an intelligent assistant to the doctors. Doctors in large hospitals have to diagnose a large dataset of images every day. This assistant will analyze all the images in the datasets and classify them as normal and abnormal. Normal Images are scrutinized with two different algorithms to improve the accuracy on false alarms.

Training

This software can be easily trained by the doctor. E.g. doctor can train it to classify what are normal and what are abnormal images. Sophisticated tools such as Neural Network, Fuzzy classifiers and State Machines are used as the Artificial Intelligence. It can be trained to detect normal and abnormal Images, also to detect a particular predefined pattern and give indication to doctors. (E.g. clusters of yellow patches as hard exudates).

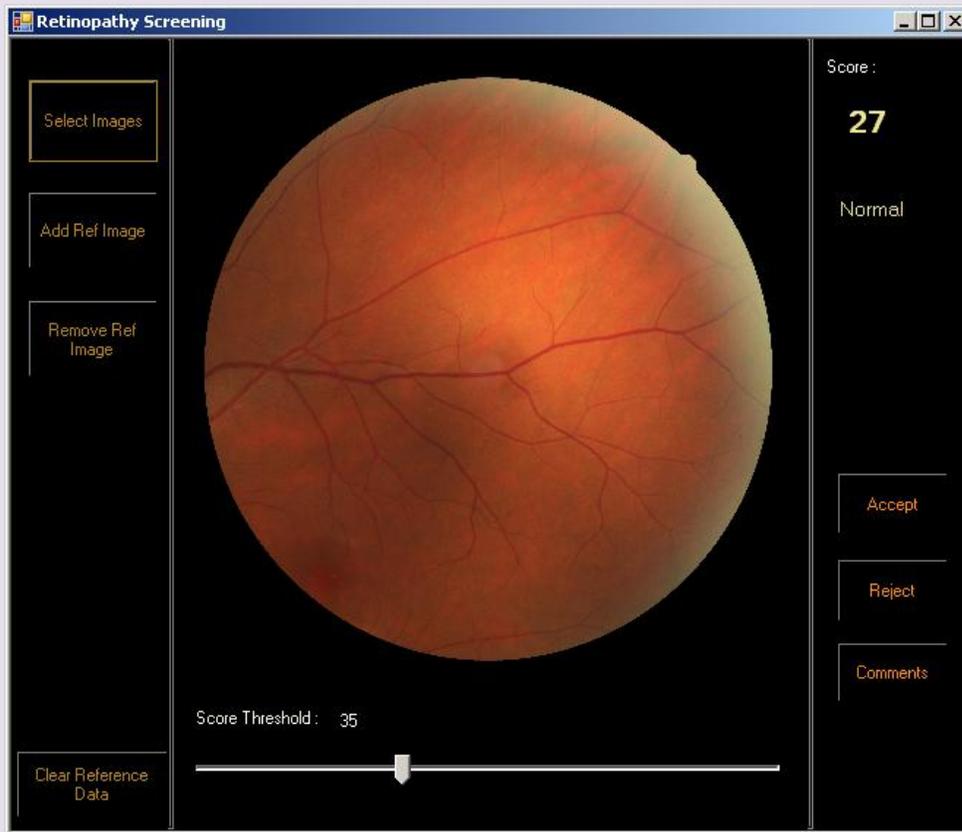


Figure 6.2 Training examples- Depending on yours feedback as Accept or Reject, algorithm will train and will give better results in future. In this way the assistant is tuned for a particular operator’s judgment (Doctor).

Intelligent Disease Locator

This is a part of algorithm that uses biological domain knowledge to extract the diseased areas. Doctors can train the algorithm to separate a particular pattern of data e.g. bleeding through a ruptured vessel. Doctors can use this knowledge for their future reference with systematic classification and their expert diagnosis. Example figure 6.1 where the Red patch is identified properly. This algorithm can be trained for all kinds of abnormal regions including as small as cluster of hard exudates.

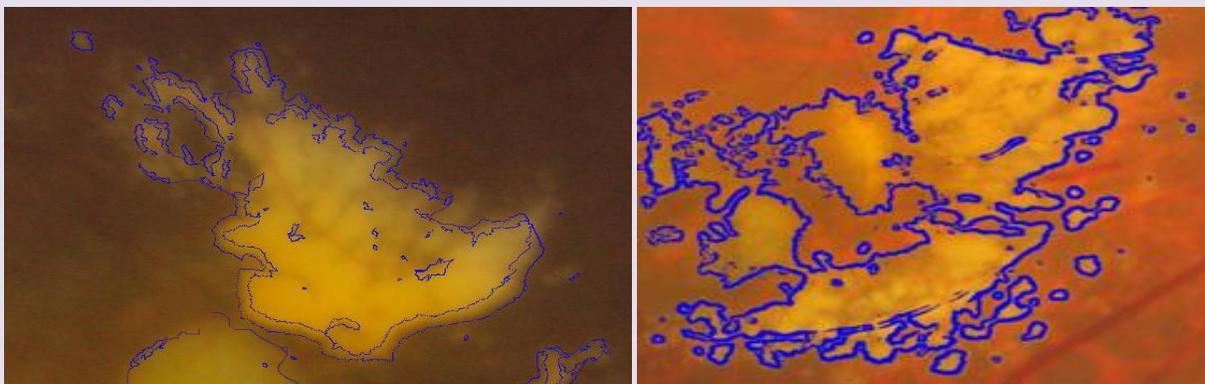


Figure 6.3 Disease Locator, Extracted boundary of the yellow Area. Used in disease Tracker.

Retinopathy Disease Tracker Tool

This tool helps scrutinize a large amount of data. Also, Doctors can view patient's medical history at fingertips (Disease Tracking). This feature will help in giving an analysis of patient's response to a particular medicine. Doctors can also view similar cases treated previously and correlate that results with current patient. For the convenience of doctors, the reports are presented with an intuitive Graphical User Interface (GUI). A few illustrations of the same are: -

- Using graphs and tables instead of just plain text
- Marking the diseased areas on the actual patient image
- Showing the statistics along with the dataset images
- Finding similar patient history case and the response to a particular medication
- Once the software is finished with the analysis, it will present the results to the doctor. Doctor can choose to accept or reject the hypothesis. These results will help the tools for self training for better diagnostic decisions in future.
- **Content based Image retrieval** can be used for identifying similar cases. E.g. doctor can select a particular image and the algorithm will identify all the images which are similar to that image from the database where doctor can have comparison.
- Doctor can share the data of a particular patient case with another in a standard format like DICOM including all the analysis and expert comments. This will enhance the **portability** of the datasets as well as the expert doctor's analysis.

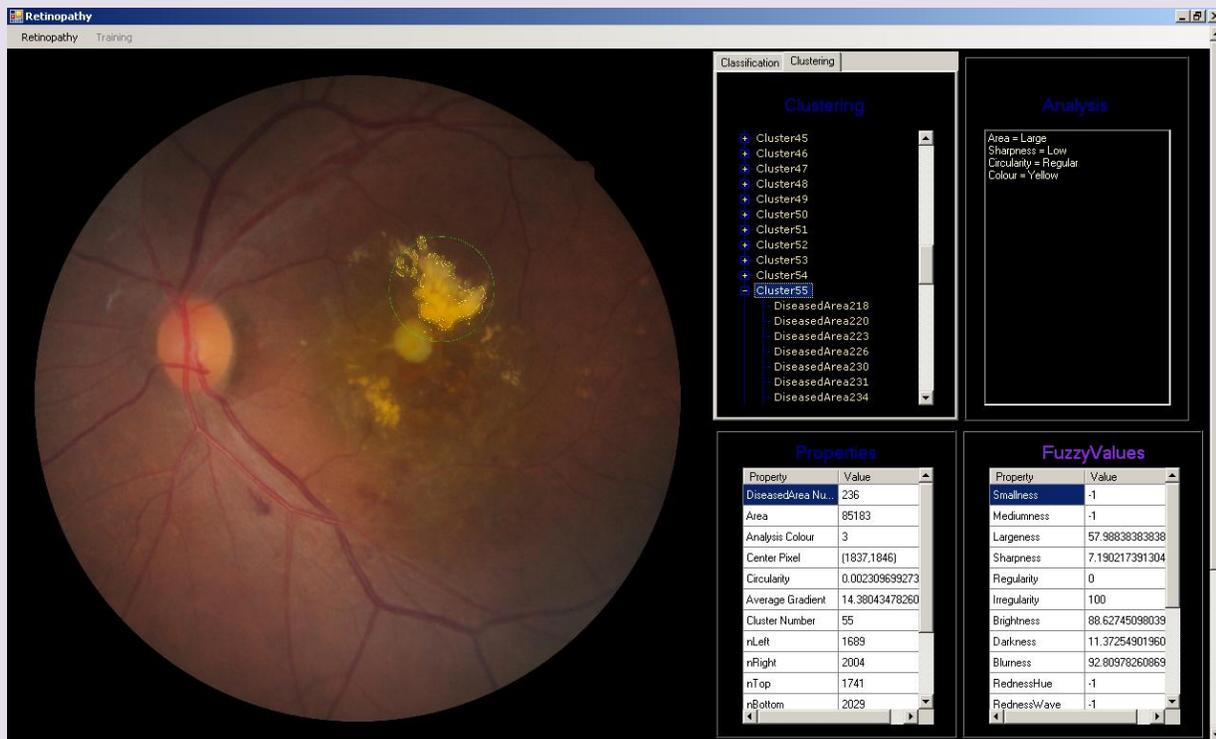


Figure 6.4 Image Showing identified diseased area along with the statistics tables.

Newly Identified Area Marked with Blue circle

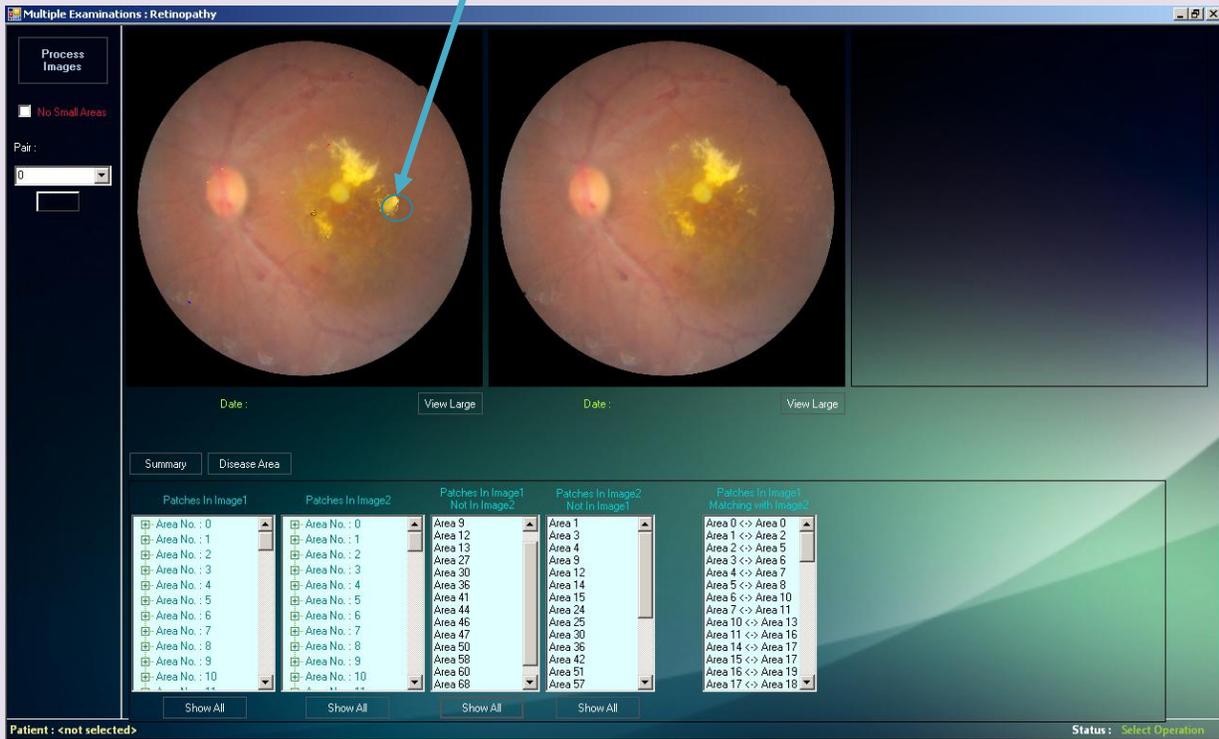


Figure 6.5 Disease Tracking Interface (in left Image new yellow spot is identified marked with blue circle, summary of the detected datasets is available in the tables shown below)

Conclusion

- Abnormal region of any shape and size can be detected using this algorithm
- Doctor can train this algorithm to detect a particular pattern from the image.
- Helps in sorting and storing the data in an easily accessible way by which doctor does not have to remember every tiny detail but has an organized way of keeping notes and using history.
- In short an intelligent and handy assistant to the doctors who can be trained for specified job.

7. Patient Database Management

Doctors require a sophisticated tool to organize the patient files in such a manner that it is easier to retrieve at any moment of time. The parameters that should be concerned for designing the database are

- Store the data sorted per patient
- Keep the Patient history easily accessible
- Keep track of the patient disease , easy visualization of comparison chart
- Sort Images as per disease database. All the patient records under a particular disease can be seen together.
- Allow multiple doctors to write their individual comments on the same file.
- Create an easily portable file format in which it will be easy to share the information.
- Generate Reports (Example report attached at the end of the document)

Currently most of the doctors exchange the information when they meet over coffee or discuss a serious case. This product will enable doctors to have expert comments from other doctors via mobile phones, emails and through websites. Doctors can get immediate notifications when they receive comments for a particular important case.

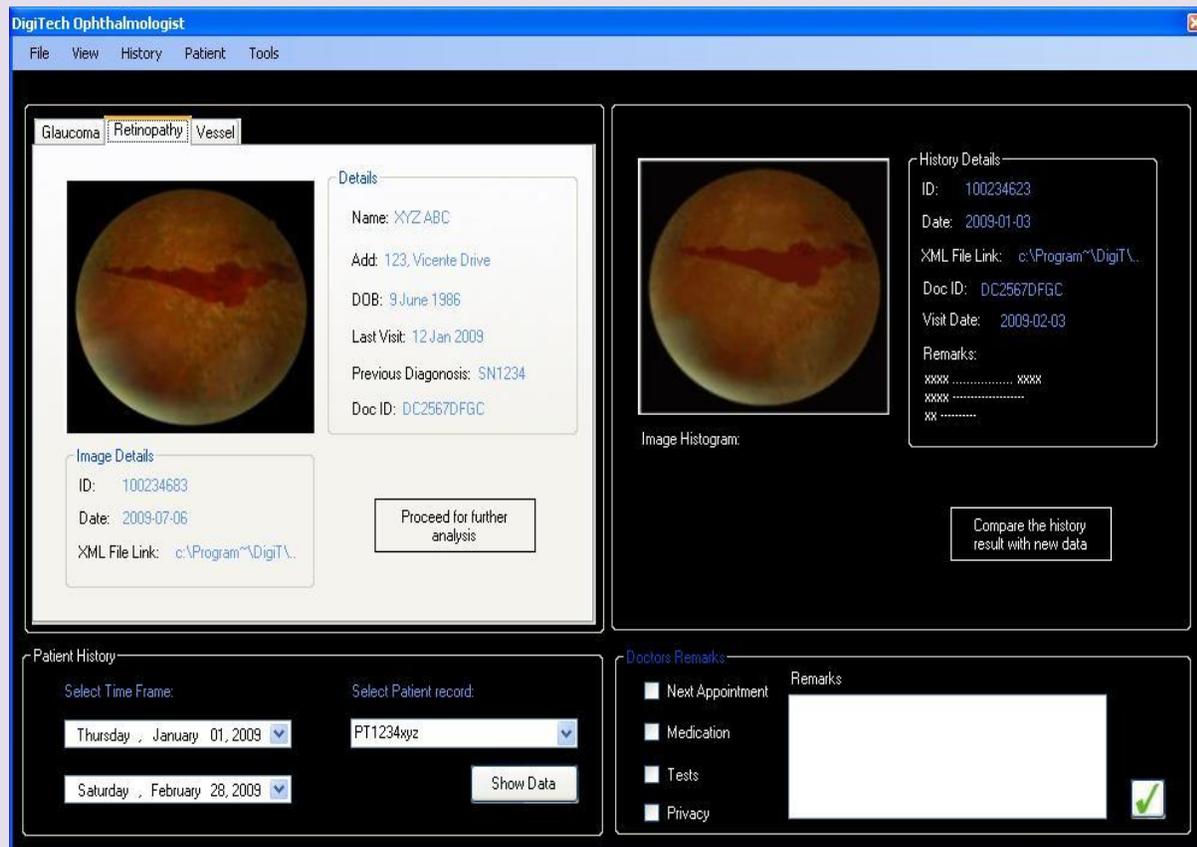


Figure 7.1 GUI Screenshot of Patient database manager

Jupiter Hospital

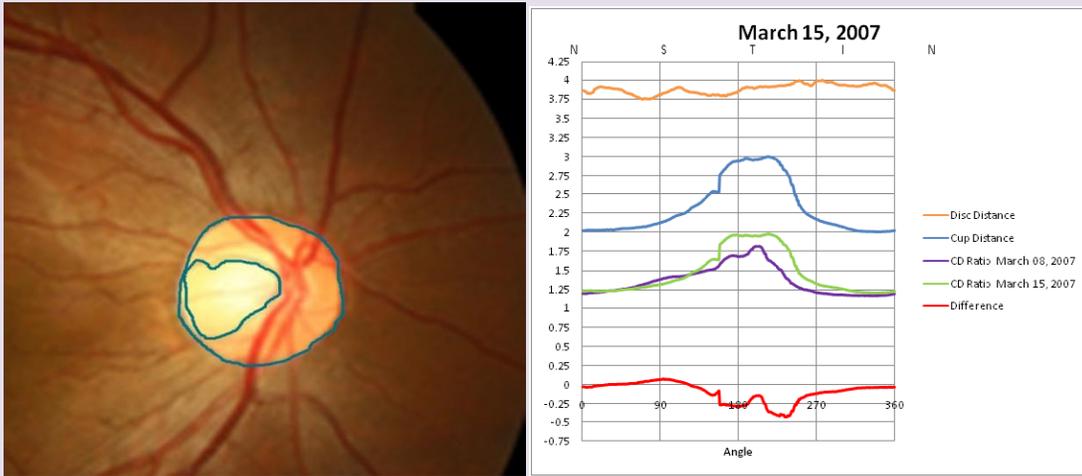
Patient Name: Mr. ABC

Medical Record #: 2112

Date: March 15, 2007

Operator: XYZ

C-D Ratio Analysis:



Software Observations

C/D:	Left: 0.3x0.4 sharp, healthy rim	Right: 0.3x0.35 sharp, healthy rim
	March 15, 2007	
C/D:	0.3x0.4 sharp, healthy rim	Right: 0.3x0.35 sharp, healthy rim
	June 29, 2006	(Horizontal and vertical cup size)

Software Analysis

Left Eye: Normal (C-D Ratio < 0.5)
Right Eye: Normal (C-D Ratio < 0.5)
Possibility of Glaucoma: **Negative**

Doctor Analysis

No Glaucoma condition observed on current day as well as history. Left & Right eye are healthy.

Dr. Kunal Gupta

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