TRACKING OF BLOOD VESSELS FOR STENOSIS DETECTION

A PROJECT REPORT

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ABSTRACT

Stenosis is the type of cardiovasular disease which accounts for large proportion of death. Computed Tomography Angiogram (CTA) modality is used for detection of cardiovascular diseases. CTA produces multiple images and diagnosis of stenosis in large images is time consuming. Hence, we propose an automated system to segment and track the coronary arteries in order to locate abnormalities present in the arteries. To segment the coronary arteries, the vesselness has to be enhanced using hessian based approach followed by morphological operators. In tracking, the vessel direction is obtained by modeling the tensors and branches are identified using the masking method. The presence of stenosis is detected while tracking based on intensity measurement and radius variation. The performance of the proposed system has been evaluated by comparing the outcome with the ground truth images given by the experts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Medical imaging is the technique and process of creating visual representations of the interior of a body for clinical analysis and medical intervention. Images obtained from Medical Imaging can be used in the field of Computer Science for early diagnosis and treatment of diseases. There are many imaging techniques for diagnosing diseases such as Computerized Tomography (CT), Magnetic Resonance Imaging (MRI) and Nuclear Medicine. The images obtained from these techniques will be of DICOM or TIFF format.

Cardiovascular disease (CVD) is a class of diseases that involve the heart or blood vessels. Some common CVDs include: Congenital Heart Disease (CHD), ischemic heart disease (IHD), stroke and peripheral artery disease (PAD). The underlying mechanisms vary depending on the disease. IHD, stroke, and PAD involve atherosclerosis. Atherosclerosis is a specific form of arteriosclerosis in which an artery wall thickens as a result of invasion and accumulation of white blood cells. These accumulations contain both living, active white blood cells and remnants of dead cells. The remnants eventually include calcium and other crystallized materials, within the outermost and oldest plaque. These will narrow the arteries and hence reduce the blood flow which will cause heart attack. This narrowing of blood vessels is called stenosis and may occur in any part in the body. Coronary artery is the one that is extensively involved stenosis. It is desirable to design efficient screening procedures for the early diagnosis and timely treatment of cardiovascular diseases. We propose an idea to detect stenosis in the coronary arteries [9].

1.1 ANATOMY AND FUNCTION OF THE CORONARY ARTERIES

Coronary arteries supply blood to the heart muscle. Like all other tissues in the body, the heart muscle needs oxygen-rich blood to function, and oxygen-depleted blood must be carried away. The coronary arteries run along the outside of the heart and have small branches that dive into the heart muscle to bring it blood.

There are two main coronary arteries are the left main and right coronary arteries. The left main coronary artery supplies blood to the left side of the heart muscle (the left ventricle and left atrium) and the right coronary artery supplies blood to the right ventricle, the right atrium.

Since coronary arteries deliver blood to the heart muscle, any coronary artery disorder or disease can have serious implications by reducing the flow of oxygen and nutrients to the heart muscle. This can lead to a heart attack and possibly death. Atherosclerosis (a buildup of plaque in the inner lining of an artery causing it to narrow or become blocked) is the most common cause of heart disease [10].

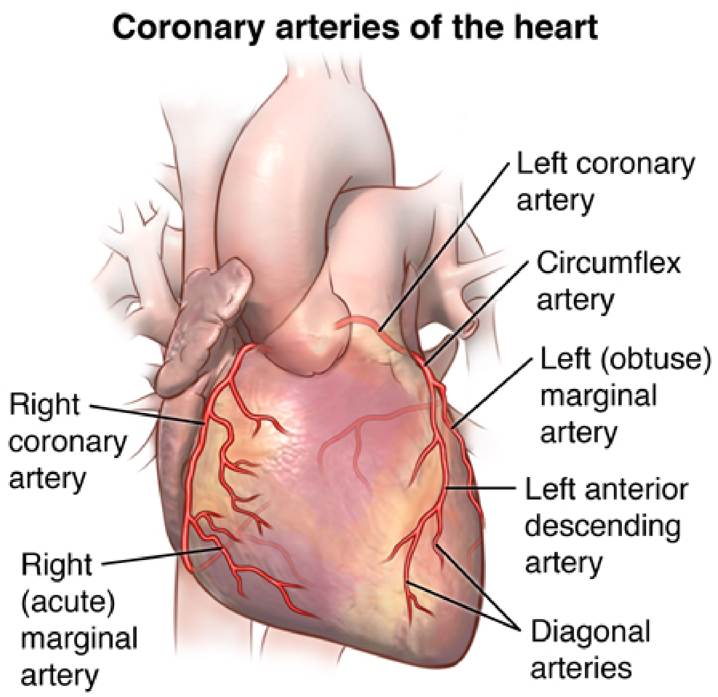

FIGURE 1.1: CORONARY ARTERY

1.2 CORONARY ARTERY DISEASE

Coronary artery disease is a result of plaque buildup in your coronary arteries - a condition called atherosclerosis - that leads to blockages. The arteries, which start out smooth and elastic, become narrow and rigid, restricting blood flow to the heart. The heart becomes starved of oxygen and the vital nutrients it needs to pump properly.

Cholesterol-laden plaque can start to deposit in the blood vessel walls from an young age. The plaque burden builds up as time passes, inflaming the blood vessel walls and raising the risk of blood clots and heart attack. The plaques release chemicals that promote the process of healing but make the inner walls of the blood vessel sticky. Then, other substances, such as inflammatory cells, lipoproteins, and calcium that travel in your bloodstream start sticking to the inside of the vessel walls.

Eventually, a narrowed coronary artery may develop new blood vessels that go around the blockage to get blood to the heart. However, during times of increased exertion or stress, the new arteries may not be able to supply enough oxygen-rich blood to the heart muscle. In some cases, a blood clot may totally block the blood supply to the heart muscle, causing heart attack [11].

1.3 IMAGING TECHNIQUES

Because coronary artery disease (CAD) is the most frequent cause of death and its onset is currently unpredictable, there is a need for new methods of screening apparently healthy individuals to identify those at increased risk. Technical advances in the noninvasive imaging techniques of computed tomography (CT), magnetic resonance imaging (MRI), and nuclear imaging now make it possible to image the heart and perform a partial evaluation of the coronary arteries.

1.3.1 COMPUTED TOMOGRAPHY

Computed tomography (CT) is an imaging procedure that uses special x-ray equipment to create a series of detailed pictures, or scans, of areas inside the body. CT has become an important tool in medical imaging. It has more recently been used for screening a disease, by taking full-motion heart scans for patients with high risk of heart disease.

CT scanning is used to detect and diagnose diseases in the head, lungs, pulmonary arteries, abdominal region. CT is often used to image complex fractures, especially ones around joints, because of its ability to reconstruct the area of interest in multiple planes. Fractures, ligamentous injuries and dislocations can easily be recognised with a 0.2 mm resolution.

ADVANTAGES

- CT completely eliminates the superimposition of images of structures outside the area of interest.
- Because of the inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1 percent can be distinguished.
- Data from a single CT imaging procedure consisting of multiple contiguous scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task.

LIMITATIONS - CONCERNS OVER RADIATION

- Levels of radiation emitted by CAT scanners vary widely, leading to the possibility of cancer as a consequence.
- X-rays also damages the DNA.

1.3.2 MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging (MRI) is a medical test that helps physicians diagnose and treat medical conditions. MRI uses a powerful magnetic field, radio frequency pulses and a computer to produce detailed pictures of organs, soft tissues, bone and virtually all other internal body structures.
Detailed MR images allow physicians to evaluate various parts of the body and determine the presence of certain diseases. The images can then be examined on a computer monitor, transmitted electronically, printed or copied to a CD.

Advantages of MRI over CAT (Computerized Axial Tomography) Scan

- CAT scan uses X rays to build up a picture. MRI uses a magnetic field to do the same and has no known side effects related to radiation exposure. The radiation from CT scans is harmful and repeated scans can even cause cancer.

- MRI gives higher detail in soft tissues.

- For purposes of tumor detection and identification, MRI is generally superior. However, CT usually is more widely available, faster, much less expensive, and may be less likely to require the person to be sedated or anesthetized.

- Another advantage of MRI is the ability to change the imaging plane without moving the patient. Most MRI machines can produce images in any plane [12].

PITFALLS OF AN MRI

Sometimes the sensitivity of MRI scans can create problems by picking up incidental findings that is, apparent abnormalities on the scan that have no actual relationship to the illness or injury being investigated. These incidental findings can cause anxiety and sometimes lead people to pursue unnecessary treatment, which may have their own risks and costs.

1.3.3 NUCLEAR MEDICINE

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases, including many types of cancers, heart disease, gastrointestinal, endocrine, neurological disorders and other abnormalities within the body. Because nuclear medicine procedures are able to pinpoint molecular activity within the body, they offer the potential to identify disease in its earliest stages.

In many centers, nuclear medicine images can be superimposed with computed tomography (CT) or magnetic resonance imaging (MRI) to produce special views, a practice known as image fusion. These views allow the information from two different exams to be correlated and interpreted on one image, leading to more precise information and accurate diagnoses.

ADVANTAGES

- Nuclear medicine examinations provide unique informationincluding details on both function and anatomic structure of the body that is often unattainable using other imaging procedures.
- For many diseases, nuclear medicine scans yield the most useful information needed to make a diagnosis or to determine appropriate treatment, if any.
- Nuclear medicine is less expensive and may yield more precise information than exploratory surgery.

LIMITATIONS

- Nuclear medicine procedures can be time consuming.
- The resolution of structures of the body with nuclear medicine may not be as high as with other imaging techniques, such as CT or MRI [13].

1.4 HEART CT SCAN

The below documentation is taken from link [9]. A computed tomography (CT) scan of the heart is an imaging method that uses x-rays to create detailed pictures of the heart and its blood vessels. It is called CT angiography if it is done to look at the arteries that bring blood to your heart.

CT rapidly creates detailed pictures of the heart and its arteries. The test may diagnose or detect:

- Plaque build-up in the coronary arteries
- Heart problems that are present at birth
- Problems with the heart valves
- Blockage of the arteries that supply the heart
- Tumors of the heart

1.4.1 CORONARY COMPUTED TOMOGRAPHY ANGIOGRAPHY (CCTA)

Angiography is a medical test that helps physicians diagnose and treat medical conditions. Patients undergoing a CCTA scan receive an iodine-containing contrast material (dye) as an injection to ensure the best possible images of the heart blood vessels. In CT angiogram, the dye is always injected into a vein first and as the dye circulates from the veins into the arteries, images are obtained.

This method displays the anatomical detail of blood vessels more precisely than ultrasound. CTA is a useful way of screening for arterial disease because it is safer and less time consuming than other methods.

ADVANTAGES

- Angiography may eliminate the need for surgery. If surgery remains necessary, it can be performed more accurately.
- CT angiography is able to detect narrowing or obstruction of blood vessels allowing for potentially corrective therapy to be done.
- CT angiography may give more precise anatomical detail than magnetic resonance imaging (MRI), particularly in small blood vessels.
- No radiation remains in a patient's body after a CT examination.
- It is also a cost-effective procedure [14].

1.5 STORAGE OF MEDICAL IMAGES

Medical imaging is the technique and process of creating visual representations of the interior of a body for clinical analysis and medical intervention. Medical imaging seeks to reveal internal structures hidden by the skin and bones, as well as to diagnose and treat disease.

1.5.1 DICOM

Digital Imaging and Communications in Medicine (DICOM) is a standard for handling, storing, printing, and transmitting information in medical imaging. It includes a file format definition and a network communications protocol. The communication protocol is an application protocol that uses TCP/IP to communicate between systems. DICOM files can be exchanged between two entities that are capable of receiving image and patient data in DICOM format.

1.5.2 TIFF

TIFF is an image format file for high-quality graphics. TIFF stands for Tagged Image Format File(TIFF). The ability to store image data in a lossless format makes a TIFF file a useful image archive, because, unlike standard JPEG files, a TIFF file using lossless compression (or none) may be edited and re-saved without losing image quality.

1.6 STENOSIS

Stenosis is an abnormal narrowing in a blood vessel or other tubular organ or structure. It is sometimes called a stricture.Stenoses of the vascular type are often associated with unusual blood sounds resulting from turbulent flow over the narrowed blood vessel. This sound can be made audible by a stethoscope, but diagnosis is generally made or confirmed with some form of medical imaging.

Stenosis can occur in any part of the body such as the spine,brain and heart. Stenosis may occur due to diabetes,atherosclerosis,smoking,inflammation or even may be a birth defect. Stenosis can be caused by a malformed valve called a bicuspid valve. Up to two percent of the population is born with a bicuspid valve abnormality which means that instead of having three flaps that open for blood flow, two are fused together. This causes blood to pass through a smaller, restricted opening.Thus, the heart has to work harder to pump blood through the valve, and the body may suffer from a reduced supply of oxygen.

Stenosis is caused by the formation of multiple atheromatous plaques within the arteries.

The plaque is divided into three distinct components:

- The atheroma - which is the nodular accumulation of a soft, flaky, yellowish material at the center of large plaques,
- cholesterol crystals,
- Calcification.

Mild instances of coronary stenosis may not have any symptoms. Once the condition become worse and the artery becomes more tapered, it can result in a tight feeling in the chest because it has to fight against clogged materials to pass blood through. It can cause difficulty in breathing, especially after physical activity, because the heart doesnt have as much oxygen from blood. If left untreated, the blood in the artery can clot and completely block it from providing the heart with blood, resulting in a heart attack [15].

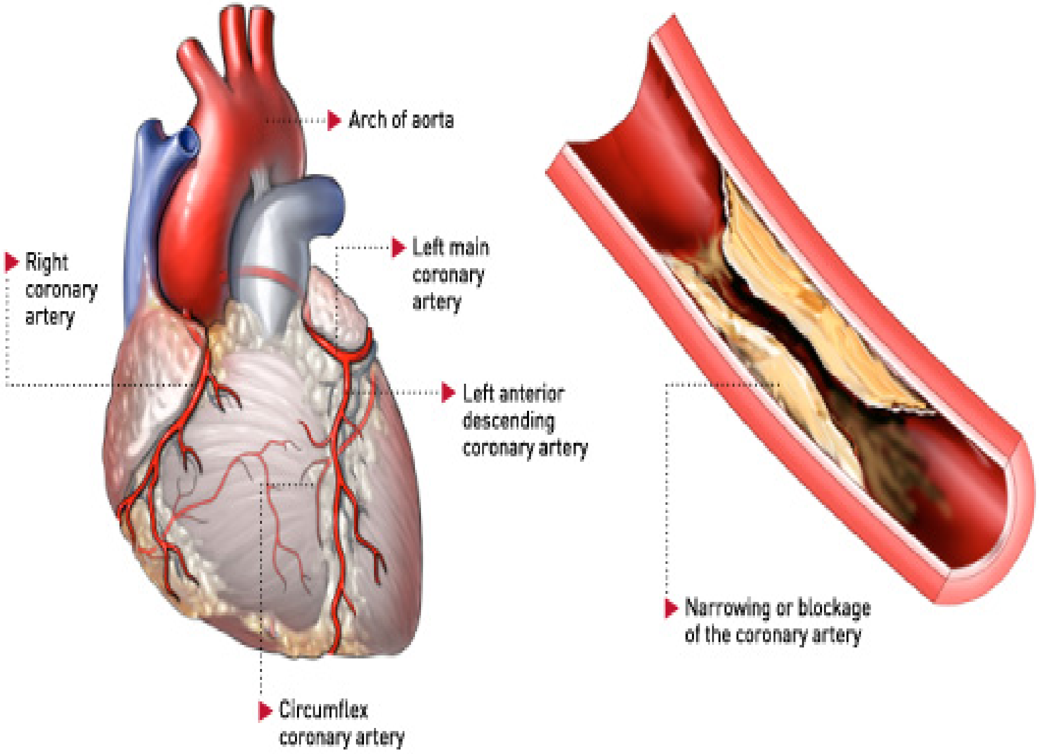

FIGURE 1.2: CORONARY ARTERY

1.7 PROBLEM STATEMENT

To design a system that segments, tracks the coronary arteries and detects the presence of stenosis.

1.7.1 OBJECTIVE

The objective is to segment the coronary artery from the 2D projection image of the heart, track the segmented vessels and then detect the probable locations of stenosis.

1.7.2 MOTIVATION

The coronary artery supplies blood to the heart muscles and obstruction within the coronary artery will reduce the flow of blood to the heart, therby causing damage and impairing its functionalities and eventually leads to heart attack.

Segmentation,tracking and stenosis detection is done using 2D projection images obtained from CTA. Detection of stenosis may take several hours for the physicians to do it manually for a single CTA dataset. Also this method is complex and expensive. So we propose a method in which segmentation, tracking and stenosis detection is done.

1.7.3 INPUT IMAGE

The input is a 2D projection image of the heart in TIFF format.

FIGURE 1.3: INPUT IMAGE

1.7.4 OUTPUT IMAGE

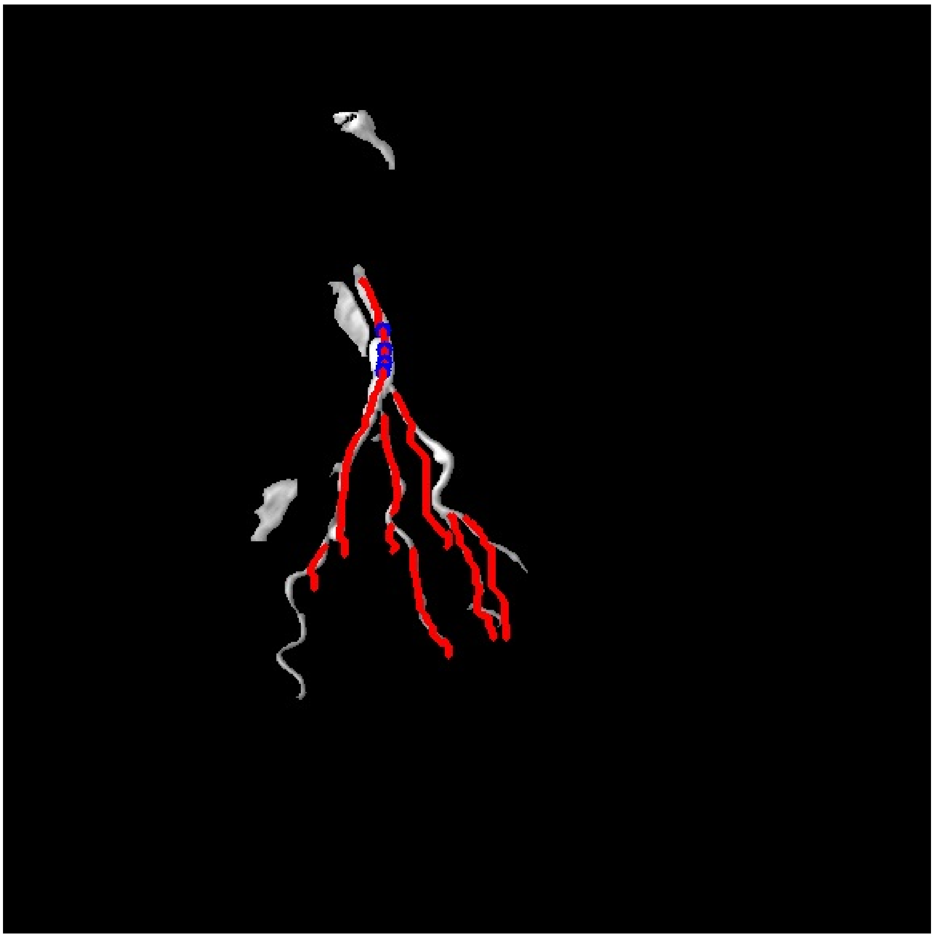

FIGURE 1.4: OUTPUT IMAGE

CHAPTER 2

LITERATURE SURVEY

[1] is examined with the purpose of developing a vessel enhancement filter. The vesselness is obtained based on the Eigen values of hessian matrix. The main purpose of [1] is to suppress the noise and background in the images while enhancing the vessel with maximum intensity. The main drawback of maximum intensity projections are the overlap of non-vascular structures and the small vessels with low contrast are hardly visible.

[2] proposes an automated determination for centre line tracking. The vessels are tracked automatically by means of a modified sector-search approach. The perimeters of sectors centered on previous tracking points are searched for the pixels with the maximum contrast. The sector size and radius are automatically adjusted based on local vessel complexity. This technique can provide a reliable basis for 2D and 3D vascular analysis. The disadvantage of this tracking is that the result will be incorrect for low signal-to-noise ratio.

A heart surface vessel segmentation and 3D reconstruction mechanism is described in [3]. De-correlation stretch algorithm is utilized for image enhancement process of the vessel ROI where the operation is to be performed. The segmentation process correctly detects the vessels even if fats cover the surface of the heart although it can be affected by the lighting conditions in the color images.

Multi-scale Hessian Matrix approach [4] is a three dimensional efficient automatic method for lung vessel segmentation. The advantage of this algorithm is that it can be used in multiple scans and has better performance with thinner slices. Hessian based approach provides a maximum value at a given scale that should match the size of the vessel and is chosen to be the intensity value. This approach finds the tubular structures in an image. The disadvantage of [4] is that maximum scale value has to be fixed in order to prevent huge computational costs of the different scaled matrices.

[5] presents a 3D image processing method that is based on the analysis of Hessian matrix combined with a multi-scale image analysis approach. The advantage of [5] is that it can operate in 2D or 3D images. However, this method was developed mainly for detecting blood vessels and cannot be directly used for airway tree detection and enhancement. Although Airway tree detection cannot be utilized in [5], it still considers the possibility to adapt for different intensity cross section profile.

[6] utilizes the concept of level sets to remove noise in the image, to enhance the image, and to track the edges of the vessels. In order to enhance and remove noise in the images, a level set method is used. For tracking, an interface is implemented which propagates through the blood vessels. The level set and fast marching methods have been researched extensively for use on medical images from brain MRIs to arteriogram. The limitation of this approach is that it is not fully autonomous for some images.

[7] proposes a tubular structure segmentation method that utilizes a second order tensor constructed from directional intensity measurements. For tracking Intensity based tensor model is used. In this method tensor matrix is formed from

which Eigen values and vectors are found to get the direction of the vessel. Vessel tractography model is extended to tubular trees by developing K-means clustering method to track along the branches. For noisy data sets the number of tensors to be considered should be greater than seven for obtaining good results. The main drawback presented in [7] is that tracking does not occur along the centre line of the vessel. To improve this situation centralization scheme is applied.

[8] presents an improvement of the watershed transform that enables the introduction of prior information in its calculation. This information is proposed by the use of a previous probability calculator. The markers have been used to combine the watershed transform and atlas registration. The algorithm is used for knee cartilage and gray matter or white matter segmentation in MR images and hence the results are accurate.

For segmentation of blood vessel, the vessel is enhanced using hessian based approach. To track along the centre line of blood vessel, vessel tractography method is utilized.To detect the branch points, 3x3 masking method is used. Finally, an automated system for detecting the presence of stenosis in CTA images is proposed.

CHAPTER 3

PROPOSED SYSTEM

3.1 OVERVIEW OF THE ARCHITECTURE

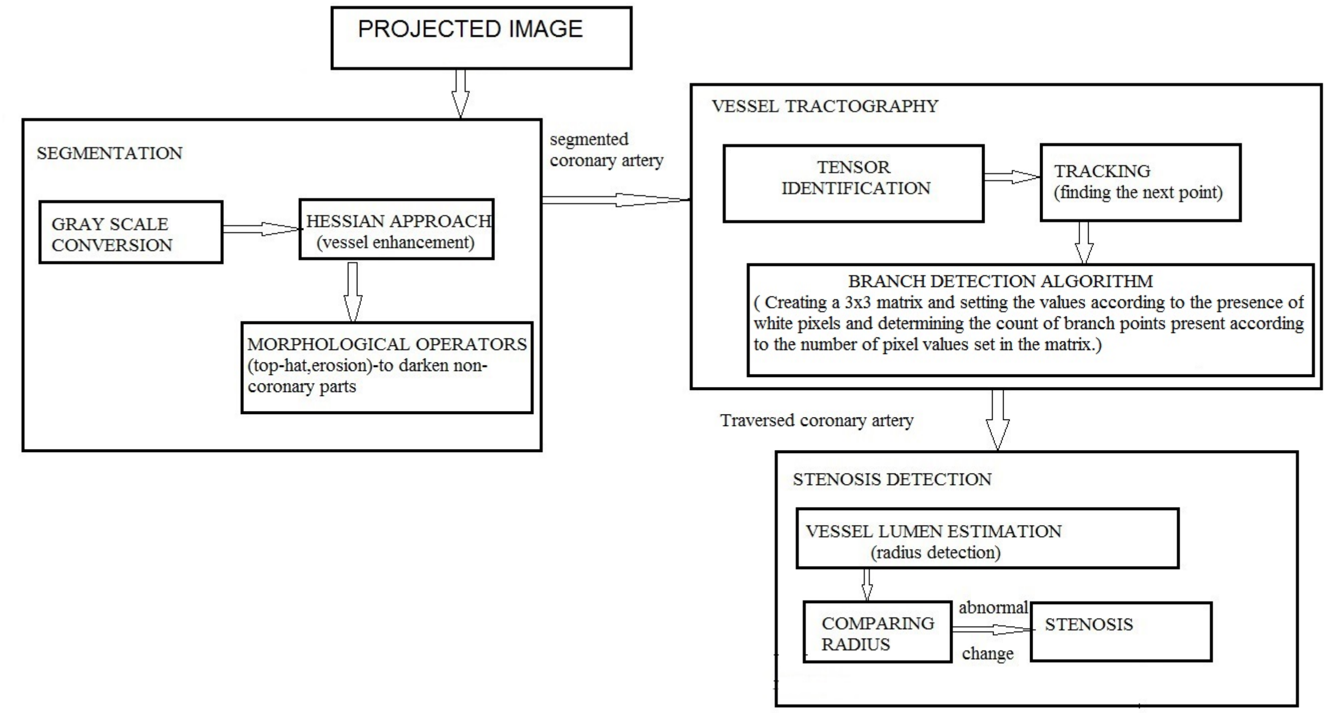

FIGURE 3.1: ARCHITECTURE DIAGRAM

Figure 3.1 shows the architecture of the whole project. In preprocessing, DICOM images of the heart obtained from CT scan are converted to TIFF image. We use 2D projection images instead of 2D image sets. For segmenting the vessels Hessian based approach is used first to enhance the image. Morphological operator, Tophat is then used to remove the non-coronary vessels.The segmented vessels are then tracked by constructing tensors.Stenosis is detected by comparing the intensity and radius of the previous and the current coordinate points.

3.2 MODULES

The whole project is split into three modules namely,

- Segmentation - The vessels are completely segmented from the input image after applying morphological operator, tophat followed by thresholding.
- Tracking - The segmented vessels are then tracked by constructing tensors.
- Detection of Stenosis - The presence of stenosis is detected using intensity and radius measurements.

3.3 PREPROCESSING

The input to the preprocessing module is 2D heart CTA image in DICOM format. Since it is difficult to process these images, they are converted to 2D projection images. The DICOM images are first converted into TIFF format using OSIRIX software. The obtained TIFF images are resized as per the requirements.

3.4 SEGMENTATION OF VESSELS

The following steps are carried out to segment the blood vessels from the heart image.

3.4.1 GRAY SCALE CONVERSION

FIGURE 3.2: GRAYSCALE RESIZED IMAGE

Input is a RGB Color Image. It converts input image from one color space to another. Figure 3.2 is the resultant gray scale image which is further used for segmenting the vessels.

3.4.2 HESSIAN BASED APPROACH

FIGURE 3.3: ENHANCED IMAGE

- Inorder to improve the vesselness, multi scale Hessian based approach have been used for image enhancement.

- The Hessian Matrix is given by 2×2 matrix

$$\begin{pmatrix} D_{xx} & D_{xy} \\ D_{yx} & D_{yy} \end{pmatrix}$$

where $D_{xx}, D_{yy}, D_{xy}, D_{yx}$ are the elements of hessian matrix. These are the second order partial derivatives of gaussian function.

- Gaussian function is given by,

$$g(x,y) = (1/\sigma\sqrt{2*\pi}) * e^{-(x^2+y^2)/(2*c^2)}$$

where x and y represents pixel co ordinates and σ is the standard deviation.

- This g(x,y) is differentiated to get Dxx ,Dyy,Dxy and Dyx. When the function g(x,y) is differentiated to get the hessian matrix elements for each pixel.

- Thus the input image is nxn and so the matrix formed is also nxn. NxN hessian matrix is then reduced to 2x2 matrix.

- This hessian matrix is convoluted with the gray scale image to obtain the enhanced blood vessels as shown in Figure 3.3.

- The main purpose of using Hessian matrix is to suppress the noise in the image background while enhancing the vessel with maximum intensity.

3.4.3 MORPHOLOGICAL OPERATIONS

Input is the enhanced image obtained by using the Hessian based approach. Morphological operator, top hat followed by thresholding is applied to the input image. Repeated thresholding is applied inorder to remove blobs from the image.

3.4.3.1 TOPHAT TRANSFORMATION

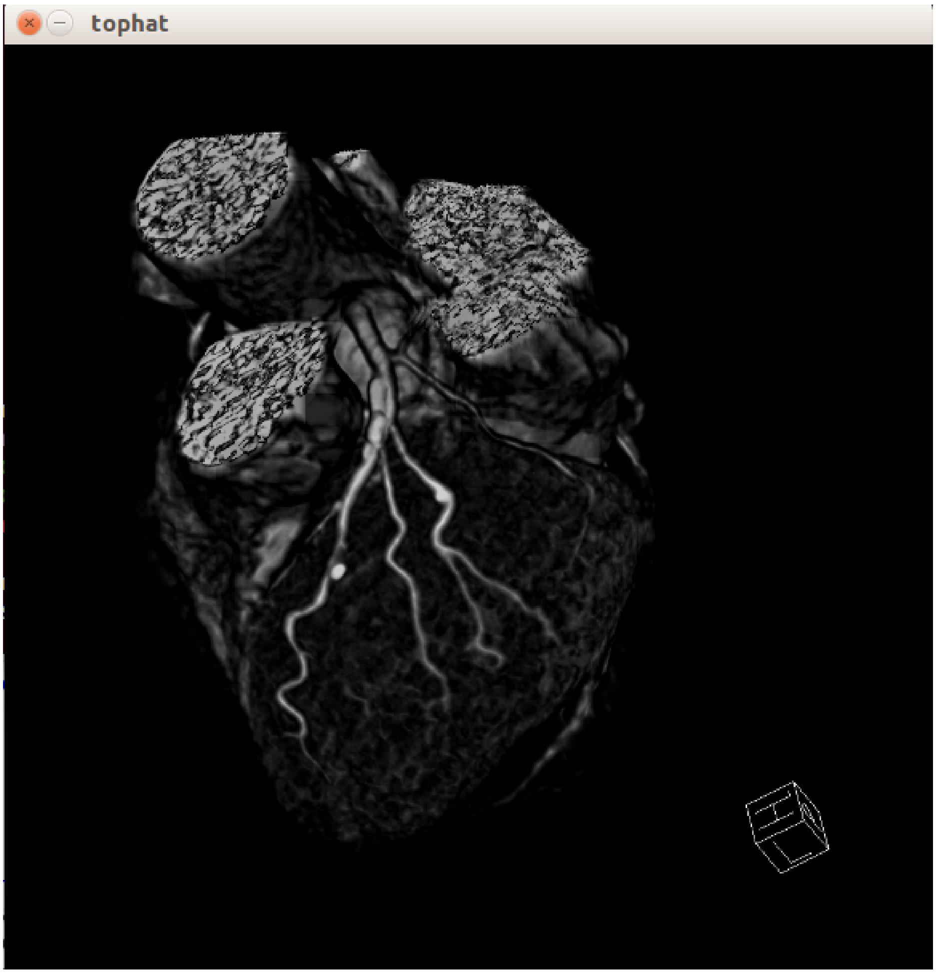

FIGURE 3.4: RESULTANT IMAGE AFTER APPLYING TOPHAT

In Tophat transformation, Erosion is followed by Dilation. Figure 3.4 shows the result of applying a top hat operator to the enhanced image. The basic effect of the erosion operator on a binary image is to erode away the boundaries of regions of foreground pixels (white pixels). Thus areas of foreground pixels shrink in size, and holes within those areas become larger. Whereas, the basic effect of the operator on a binary image is to gradually enlarge the boundaries of regions of foreground pixels (white pixels). Thus areas of foreground pixels grow in size while holes within those regions become smaller.

3.4.3.2 THRESHOLDING

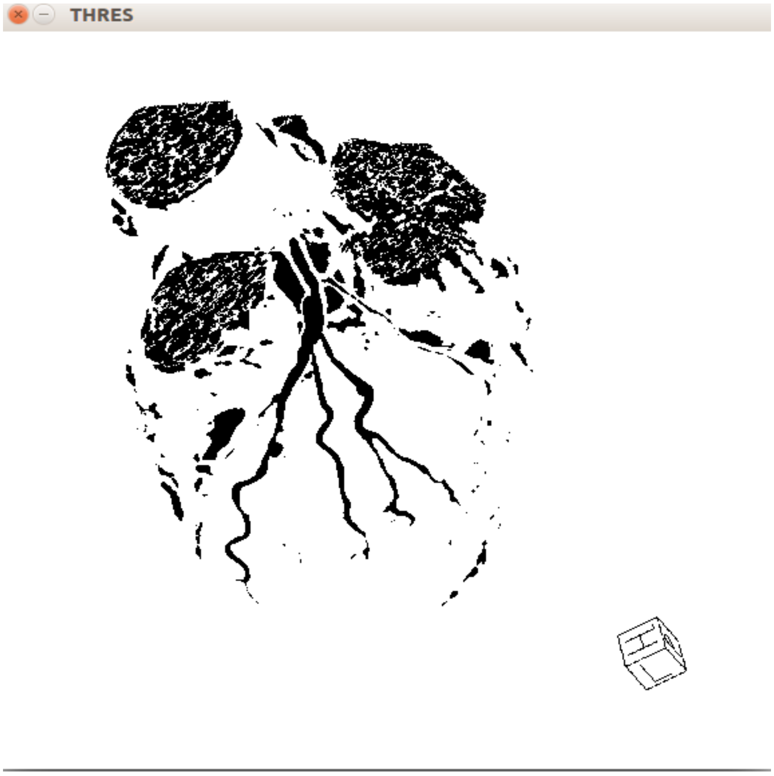

FIGURE 3.5: RESULTANT IMAGE AFTER THRESHOLDING

Input is the resultant image of the tophat transformation. Thresholding is applied to the input image.The simplest thresholding methods replace each pixel in an image with a black pixel if the image intensity is less than some fixed constant T, or a white pixel if the image intensity is greater than that constant. Figure 3.5 is the resultant image obtained after applying threshold.

3.4.3.3 FINAL SEGMENTED VESSELS

The blobs if present in the image when thresholding is applied are removed. The output image has the segmented vessels. Figure 3.6 shows the final segmented vessels.

FIGURE 3.6: SEGMENTED VESSELS

3.5 VESSEL TRACTOGRAPHY

The segmented vessel is then tracked by following the methods given below.

3.5.1 SKELETONISATION

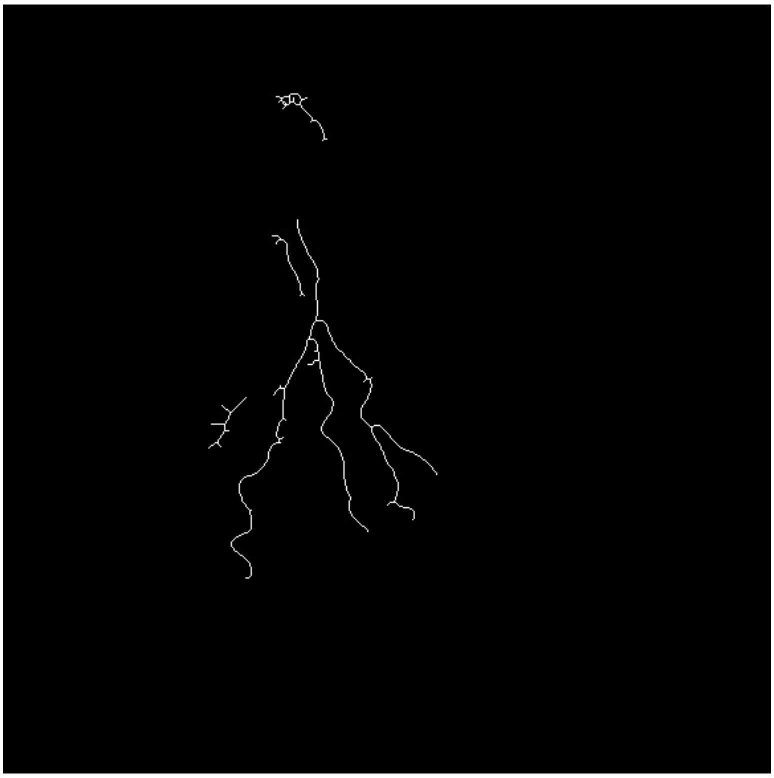

FIGURE 3.7: SKELETONISED IMAGE

Input is the segmented blood vessels. Skeletonisation is applied to the input image to get the centerline of the vessels for tracking purposes. Figure 3.7 shows the skeletonised image.

- A morphological skeleton can be computed using the two basic morphological operations: dilate and erode.

- The skeleton can be produced by morphological thinning that successively erodes away pixels from the boundary (while preserving the end points of line segments) until no more thinning is possible, at which point what is left approximates the skeleton.

3.5.2 FINDING CONTOURS

Input is the skeletonised image. It represents the bounding shape in the image. The first and the last points are found for the given contour. This first point is assumed to be the initial seed point for tracking the coronary arteries.

3.5.3 TRACKING

To track the blood vessels, tensors are used to find the direction of blood vessel.The Tensor Matrix is given by 2×2 matrix

$$\begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix}$$

.

3.5.3.1 CREATING TENSOR

- The tensor moves in three directions. To construct a tensor, a circle is created that is enclosed in a rectangle.

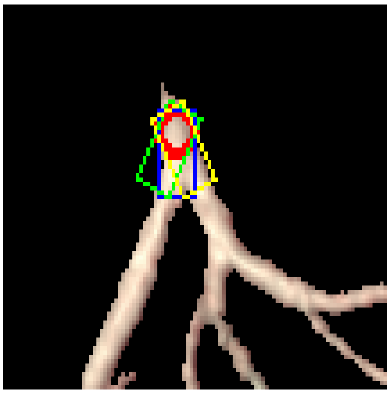

FIGURE 3.8: TENSOR CONSTRUCTION - CIRCLE AND RECTANGLES

- With the seed point as center a circle is drawn with the best fit radius.
- To determine the best fit radius, 2-NORM ($d^t * d$) of tensor matrix is found.
- From the resultant matrix of $d^t * d$, maximum eigen value (λ_{max}) is found.
- The square root of λ_{max} is found.
- This procedure is carried out for different radius values (r_{min} to r_{max}).
- The radius value for which λ_{max} is maximum is set as the radius of the circle for the considered point.
- Three rectangles are constructed in which one is vertical and the other two are rotated at given angles as shown in Figure 3.8.

3.5.3.2 CALCULATING INTENSITY MEASUREMENT M_i

Intensity measurement M_i is given by, $M_i = (\mu\Omega_1 - \mu\Omega_2)^2$

- Ω_1 is the region of the circle.

- Ω_2 region of the (rectangle-circle) area.

- M_i is the square of (mean intensity of circle - mean intensity of (rectangle-circle) area).

- Calculate $M_i$in three directions.

- The resulting matrix is a column matrix of order 3x1.

$$\begin{pmatrix} M_1 \\ M_2 \\ M_3 \end{pmatrix}$$

.

3.5.3.3 INTENSITY CALCULATION FOR CIRCLE

- Find points along the circumference of the circle. Consider the circle to be two semi circles.

- Using circumference points of the upper semicircle and the lower semi circle,traverse line by line covering the entire region of the circle and thereby finding the intensity of the entire circle.

- The intensity values obtained from the previous step are added and is divided by the total number of pixels inside the circle which gives the intensity mean of the circle.

3.5.3.4 INTENSITY CALCULATION FOR RECTANGLE

- Using the vertices and points on the perimeter of the rectangle,traverse line by line to cover the entire region of the rectangle and thereby finding the intensity of the entire region.
- The mean intensity values of the regions are calculated accordingly.

3.5.4 TENSOR MATRIX CREATION

- To calculate the orientational vector,find the point on the circumference of the circle at which the rectangle has been rotated.
  - Subtract this value from the center point of the circle to get the direction vector.
  - The same process is done for the rest of the two directions.
  - Orientation vectors along the three directions g_1, g_2, g_3 are obtained.
- To construct the H matrix,the intensity mesurement can be modelled as $Mi = g_i^T * D * g_i$
  - This equation is rearranged to $Mi = H_i * d$
  - Using values of orientation vectors g_1, g_2, g_3 H matrix can be constructed.

  The H Matrix is of order 3×3 matrix

$$\begin{pmatrix} g_{1x}^2 & g_{1y}^2 & 2g_{1x}g_{1y} \\ g_{2x}^2 & g_{2y}^2 & 2g_{2x}g_{2y} \\ g_{3x}^2 & g_{3y}^2 & 2g_{3x}g_{3y} \end{pmatrix}$$

.

- Tensor matrix is constructed using formula $d = (H^T H)^{-1} H^T M$
  The resulting matrix is of order 3*1 which is given by.

$$\begin{pmatrix} d_{11} \\ d_{22} \\ d_{12} \end{pmatrix}$$

.

- Since tensor matrix D is symmetric , the tensor matrix of order 2x2 can be constructed.

$$\begin{pmatrix} d_{11} & d_{12} \\ d_{12} & d_{22} \end{pmatrix}$$

.

- Single Value Decomposition method is used to obtain non-negative eigen values and corresponding eigen vectors.

- The smallest eigen value's vector is added to the current co-ordinate

- This method is repeated till all vessel branches are traversed.

3.5.5 BRANCH DETECTION ALGORITHM

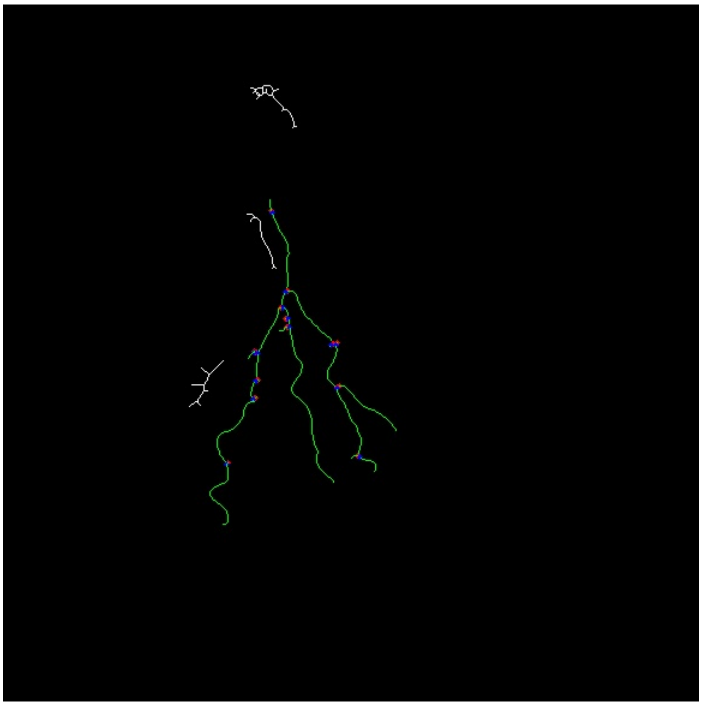

FIGURE 3.9: BRANCHPOINTS

- Branch Detection Algorithm method detects the presence of branches and its count.
- By thinning algorithm, segmented blood vessels are reduced to unit width pixel.
- A 3x3 matrix is created at a current coordinate where the current coordinate is the center of the matrix.
- The matrix values are checked for the presence of white pixels.If there exists white pixels then the count is incremented.
- If the count is three, this means that tracking is done along the centerline of the vessel.

- If the count is four or more, then branches are indicated.These values are stored for tracking purposes.
- If the count is two, then this is an end point.
- The stored branch points are then given as the seed points for vessel tracktography.
- The branch points are shown in Figure 3.9

3.6 STENOSIS DETECTION

- For stenosis detection, there exists two different cases.

  CASE 1

  - The radius of the current coordinate is compared with the previous coordinate while tracking.
  - If there is an abnormal change in the radius, then there exists stenosis.

  CASE 2

  - CASE 1 along with the higher intensity variation of the current coordinate should be satisfied to ensure presence of stenosis.

STENOSIS

The presence of stenosis is shown by the rounded blue circles in Figure 3.10

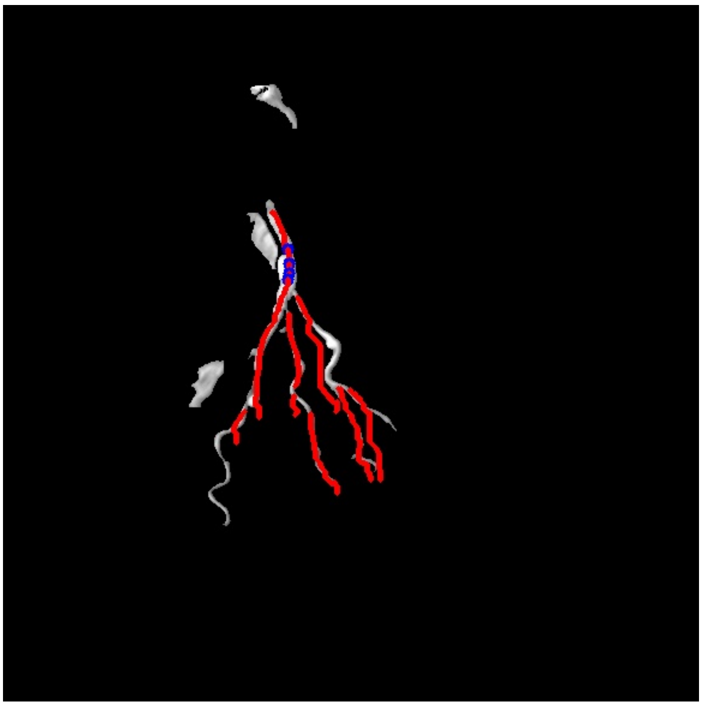

FIGURE 3.10: STENOSIS

CHAPTER 4

EVALUATION AND RESULTS

4.1 EXPERIMENTAL SETUP

Experiments are carried out by collecting 2D projection images of 10 different patients from Billroth Hospitals in DICOM format. The CTA images of heart were obtained using different angiographic views and rotations from SOMATOM 64-slice CT scanner. For each patient 8-10 projection images were considered. The images include those with high degree of stenosis, low degree of stenosis and also images without stenosis.The whole system was implemented using OpenCV.

4.2 PERFORMANCE ANALYSIS

The system was evaluated based on the ground truth obtained from experts for stenosis detection. To evaluate the performance of the proposed system, we have used precision, recall and F1 score as evaluation criteria.The performance parameters are computed and are shown in the Table 4.1

1. True Positive(TP): if case is positive and prediction is positive.

2. False Positive(FP): if case is negative but prediction is positive.

$$Precision(p) = \frac{TruePositives}{\text{True Positives + False Positives}} \tag{4.1}$$

$$Recall(r) = \frac{TruePositives}{\text{Total number of positive samples}} \tag{4.2}$$

$$F1Score = \frac{\text{2 x p x r}}{\text{p + r}} \tag{4.3}$$

TABLE 4.1: PERFORMANCE EVALUATION

Patient	Positive cases	Positive predictions	True Positive	False Positive	Precision	Recall	F1 Score
P1	2	2	2	1	0.66	1	0.79
P2	1	1	1	1	0.5	1	0.66
P3	3	3	3	2	0.6	1	0.75
P4	2	2	1	1	0.5	0.5	0.5
P5	5	4	3	0	1	0.6	0.75
P6	4	3	2	0	1	0.5	0.66
P7	7	6	5	2	0.7	0.71	0.70

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

An automated system has been successfully designed to segment and track the coronary arteries for stenosis detection. For segmentation, vessel enhancement is achieved by hessian based approach and non coronary arteries are removed by morphological operators. Then tracking is done by modelling the tensors to move along the vessel direction. Finally stenosis is identified by radius and intensity variation.

5.2 FUTURE WORK

The automated system that we have implemented gives good True Positive results. Due to the limited features considered for stenosis detection false positive results are found to be slightly higher. This problem can be overcome by extracting more features and train the system using any machine learning technique to detect stenosis.

CHAPTER 6

APPENDIX

OpenCV (OPEN SOURCE COMPUTER VISION)

OpenCV is the leading open source library for computer vision, image processing, machine learning and GPU acceleration for real-time operation. OpenCV was developed by Intel. Since OpenCV is released under a BSD license it is free for both commercial and non-commercial use. It is a library of many inbuilt functions mainly aimed at real time image processing. It includes C++, C, Python and Java interfaces and supports Windows, Linux, Mac OS, iOS as well as Android.

MODULES

The different modules of OpenCV are given below.

core

It is the basic module of OpenCV which includes basic data structures (e.g.-Mat data structure) and basic image processing functions. This module is also extensively used by other modules like highgui.

highgui

This module provides simple user interface capabilities like image and video capturing capabilities,manipulating image windows, handling track bars and mouse events and others.

imgproc

This module includes basic image processing algorithms including image filtering, image transformations, color space conversions and some others.

video

This is a video analysis module which includes object tracking algorithms, background subtraction algorithms.

objdetect

This includes object detection and recognition algorithms for standard objects.

FUNCTIONALITIES

- Image/video I/O, processing, display (core, imgproc, highgui).
- Object/feature detection (objdetect, features2d, nonfree) .
- Geometry-based monocular or stereo computer vision (calib3d, stitching, videostab).
- Computational photography (photo, video, superres) .
- Machine learning and clustering (ml, flann) .
- CUDA acceleration (gpu) .

ADVANTAGES

- It has several hundreds of image processing and computer vision algorithms for developing advanced computer vision applications which are easy and efficient.
- It was designed for computational efficiency with a strong focus on real-time applications.
- With an optimized C/C++ code, the OpenCV library can take advantage of multi-core processing.

APPLICATIONS

OpenCV is being used for a very wide range of applications which includes:

- Street view image stitching.
- Automated inspection and surveillance.
- Robot and driver-less car navigation and control.
- Medical image analysis.
- Video/image search and retrieval.
- Movies - 3D structure from motion.
- Interactive art installations.

OpenCV Installation

Prerequisites:

The prerequisites that are required to install opencv are

- Ubuntu - version 14.10
- cmake - version 2.8
- make version 4.0

Installation steps:

The steps that are involved in installation process are:

- To update Ubuntu, use the following command in the terminal sudo apt-get update && sudo apt-get upgrade && sudo apt-get dist-upgrade && sudo apt-get autoremove.
- Then install all the dependencies like build tools,gui,media I/O and video I/O by the following commands in the terminal. sudo apt-get install build-essential cmake
  - sudo apt-get install qt5-default libvtk6-dev
  - sudo apt-get install zlib1g-dev libjpeg-dev libwebp-dev libpng-dev libtiff5-dev libjasper-dev libopenexr-dev libgdal-dev
  - sudo apt-get install libdc1394-22-dev libavcodec-dev libavformat-dev libswscale-dev libtheora-dev libvorbis-dev libxvidcore-dev libx264-dev yasm libfaac-dev libopencore-amrnb-dev libopencore-amrwb-dev libv4l-dev libxine-dev
- Download the latest version of OpenCV for linux from the website(http://opencv.org/).
- Open the terminal and goto OpenCV directory .

To compile and install type the following commands,

mkdir build && cd build

cmake -DWITH_QT=ON -DWITH_OPENGL=ON -DFORCE_VTK=ON
-DWITH_TBB=ON -DWITH_GDAL=ON -DWITH_XINE=ON
-DBUILD_EXAMPLES=ON ..

make -j4

sudo make install

To configure OpenCV, type sudo ldconfig

Now the OpenCV will be successfully installed.

Compile and Execution of Sample example:

- Type the code and save as sample.cpp in a folder named test inside the home directory.
- Create a text file named CMakeLists.txt with the following code:

cmake_minimum_required(*VERSION*2.8.12)
project(sample)
find_package(OpenCV REQUIRED)
include_directories($ { OpenCV_INCLUDE_DIRS })

```
add_executable(sample sample.cpp)
target_link_libraries(sample $OpenCV_LIBS)
```

To build and execute, type the following commands

```
mkdir test
cmake .
make
./demo
```

OpenCV library functions:

Mat() - To create a Mat object.

IplImage* cvCreateImage(CvSize size, int depth, int channels)
size - Image width and height.
depth - Bit depth of image elements.
channels - Number of channels per pixel.

CvMat* cvCreateMat(int rows, int cols, int type)
rows - Number of rows in the matrix.
cols - Number of columns in the matrix.
type - The type of matrix elements in the form.

cvCopy(const src, const dst)
src - the source array.
Dst - the destination array.

void cvSet(CvArr* arr, CvScalar value, const CvArr* mask=NULL)
cvSet() - Sets every element of an array to a given value.
arr - The destination array
value - Fill value
mask - Operation mask, 8-bit single channel array;
specifies elements of the destination array to be changed.

cvReduce(src, dst, dim, CV_REDUCE_SUM)
The inbuilt cvReduce has the following five arguments.
The five arguments are

1.Input 2D matrix,
2.Output vector,
3.Dimension index along which the matrix is reduced (0 means that the matrix is reduced to a single row. 1 means that the matrix is reduced to a single column.),
4.Reduction operation - the output is the sum of all rows/columns of the matrix.
5.Depth - the last parameter, when negative, the output vector will have the same type as the input matrix.

cvFilter2D(const CvArr* src, CvArr* dst, const CvMat* kernel, CvPoint anchor=cvPoint(-1,-1))
Convolves an image with the kernel.
(To convolute Hessian matrix and gray scale image to get Hessian image)

The filter2D method has five parameters namely;
1.Input image - grayscale image,
2.Output image of the same size and the same number of channels as the input image,
3.Desired depth of the destination image,

4.Kernel - Hessian matrix,
5.Anchor of the kernel that indicates the relative position of a filtered point within the kernel.

void cvEigenVV(CvArr* mat, CvArr* evects, CvArr* evals, double eps=0, int lowindex=-1, int highindex=-1)
cvEigenVV() calculates eigen value and eigen vector of a symmetric matrix.
src input matrix that must have CV_32FC1 or CV_64FC1 type.
eigenvalues - output vector of eigenvalues of the same type as src; the eigenvalues are stored in the descending order.
eigenvectors - output matrix of eigenvectors; it has the same size and type as src; the eigenvectors are stored as subsequent matrix rows, in the same order as the corresponding eigenvalues.
lowindex - optional index of largest eigenvalue/-vector to calculate; the parameter is ignored in the current implementation.
highindex - optional index of smallest eigenvalue/-vector to calculate; the parameter is ignored in the current implementation.

void cvTranspose(const CvArr* src, CvArr* dst)
cvTranspose() transposes a matrix
src - input array.
dst - output array of the same type as src.

cvMatMul(CvArr *mat1, CvArr *mat2, CvArr *result)
cvMatMul() - to multiply two matrices
where, mat1 - first array
mat2 - second array
result - resultant array.

cvInv(const CvArr *src, const CvArr *dst, int method)

cvInv() - to find the inverse of the matrix.

where, src - source matix

dst - destination matrix

method - inversion method opencv has couple of methods CV_LU the LU decomposition method and CV_SVD based on singular value decomposition method.

REFERENCES

1. Alejandro F. Frangi, Wiro J. Niessen, Koen L. Vincken and Max A.Viergever (2006) ‘ Multiscale vessel enhancement filtering in Image Sciences Institute’, vol no.1496, pp 130-135.

2. Anindya Sen, Li Lan, Kunio Doi, and Kenneth R. Hoffmann (1999) ‘Quantitative evaluation of vessel tracking techniques on coronary angiograms’, Medical Physics, vol. 26, no. 5, pp 698-705.

3. Aqeel Al-Surmi, Rahmita Wirza, Ramlan Mahmod, Fatimah Khalid and Mohd Zamrin Dimon (2014)‘ A new human heart vessel identification, segmentation and 3D reconstruction mechanism ’, pp 1-4.

4. Ilkay Oksuz ‘Multi-scale Hessian based approach for segmentation of lung vessel tree in 3-D CTA data ’, pp 1-2.

5. Marcin Rudzki (2009) ‘Vessel Detection Method Based on Eigenvalues of the Hessian Matrix and its Applicability to Airway Tree Segmentation’, pp 100-105.

6. P. Echevarria,T. Miller and J.O’Meara (2004) ‘Blood Vessel Segmentation in Retinal Images’, Journal of Cardiothoracic Surgery, 9:161, pp 1-9.

7. Suheyla Cetin , Ali Demir, Anthony Yezzi, Muzaffer Degertekin, and Gozde Unal (2012) , ‘Vessel Tractography Using an Intensity based Tensor Model with Branch Detection’, IEEE transactions on medical imaging, vol no. 32, no. 2, pp 1-6.

8. V. Grau, A. U. J. Mewes, M. Alcaniz,R. Kikinis and S. K. Warfield (2004) ‘Improved Watershed Transform for Medical Image Segmentation Using Prior Information’, vol. 23, pp 2-6.

9. http://en.wikipedia.org/wiki/Cardiovascular_disease
10. http://www.hopkinsmedicine.org/healthlibrary/conditions/cardiovascular _diseases/anatomy_and_function_of_the_coronary_arteries
11. http://www.webmd.com/heart-disease/guide/heart-disease-coronary-artery-disease.
12. http://www.nps.org.au/medical-tests/medical-imaging/for-individuals/types-of-imaging
13. http://www.radiologyinfo.org
14. http://www.radiologyinfo.org/en/info.cfm
15. http://www.heart.org/HEARTORG/Conditions/More/HeartValveProblemsandDisease/Problem-Heart-Valve-Stenosis