K–Means Clustering based Angiographic Image Analysis to Measure Coronary Stenosis

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ABSTRACT

Medical imaging uses techniques or processes which use human body images for clinical or medical science. Medical imaging has a wide range of applications in the field of radiology, angiography and angiogram imaging. Nowadays, angiography and computerized tomography (CT) scans are two common methods that are used by doctors for the detection of coronary artery stenosis (artery blockage) in medical imaging.

Most of the detection processes in medical imaging are performed by analyzing digital images generated through angiography and CT scan processes. Currently most of the diagnoses are performed by doctors after manual inspection of real time frames of the video generated by the respective medical imaging systems.

In this thesis we propose to use digital image processing techniques in detection and categorization of the clogs in the arteries (stenosis/blockage) by using the frames generated from the X-ray angiography. Utilized image pre-processing methods includes selecting a line of Interest (LOI) on blocked vessel and further selection of the region of interest (ROI) on that area, then automatically cropping the region of interest followed by Gaussian filtering for smoothing. In the post processing, three alternative methods are proposed to measure the stenosis in the vessel. The first method applies thresholding to extract the vessel of interest. The extracted vessel is analyzed for the calculation of the stenosis in percentage. The second method utilizes segmentation of the vessel tissue over the extracted pixels of ROI. The final method uses K-means clustering to differentiate between the vessel regions and non-vessel regions. Among the proposed methods K-means clustering based method outperforms the thresholding and segmentation methods.

The performance of the proposed methods is compared with the manually measured objective results and doctor's opinion which can be considered a subjective score. The results indicate that the proposed methods are reliable alternatives to aid the doctors in deciding reliable stenosis scores. K-means based method produces the best average performance on the evaluated vessels with stenosis. A new metric, Maximum Percentage Error Ratio (MPER), in decibels is proposed to indicate the quality of the decisions regarding the generated stenosis (%) using different methods. K-means based method generates the highest performance in terms of MPER.

Keywords: Medical image processing, X-ray angiography, angiography imaging, segmentation, thresholding, K-means clustering, stenosis in heart vessels.

ÖZ

Tıbbi görüntülemede insan vücuduna ait imgeler farklı teknikler ve süreçler ile klinik ve tıbbi bilim tarafından kullanılmaktadır.Tıbbi görüntüleme radyoloji, anjiografi ve anjiyogram görüntüleme alanında geniş bir uygulama yelpazesine sahiptir. Günümüzde, anjiyografi ve bilgisayarlı tomografi (BT) taramaları tıbbi görüntülemede koroner damar darlığı (damar tıkanıklığı) tespiti için doktorlar tarafından kullanılan iki yaygın yöntemlerdir.

Tıbbi görüntüleme algılama süreçlerinde genellikle anjiyografi ve BT tarama ile üretilen sayısal görüntüler analiz edilmektedir. Günümüzde, doktorlar muayene sırasında tanı ortaya koyabilmek için ilgili medikal görüntüleme sistemleri tarafından üretilen video çerçeve imgelerini kullanmaktadırlar.

Bu tezde, sayısal imge işleme teknikleri kullanarak X-ışını kaynaklı anjiyografi imgelerini işlenerek damar darlığı (damar tıkanıklığı) tespiti ve sınıflandırılması için kullanılmasını öneriyoruz. Kullanılan görüntü işleme yöntemleri sırasıyla: daralmanın oluştuğu damar üzerinden ilgi çizgisinin seçimi (LOI), bu çizgi etrafında ilgi alanının çıkarımı (ROI) daha sonra bu bölgenin kırpılması ile daha sonraki işlemler için ön işlem tamamlanır. Sonraki aşamada, Gauss filtresi kullanılarak bölge düzgünleştirilir. Düzgünleştirilen imgedeki damar içerisindeki daralmanın ölçülebilmesi için üç farklı yöntem onerilmektedir. İlk yöntem, ilgi konusu damarın çıkarımı için eşikleme yöntemi uygulamaktadır. Çıkarılan damar imgesi analiz edilerek damar daralması yüzdelik olarak hesaplanmaktadır. İkinci yöntem ROI üzerinden eşiklenerek çıkarılan piksellerin gerçek değerlerinin bölütleyerek damar daralmasını hesaplamaktadır. Önerilen, son yöntemde K-ortalamalar kümeleme yöntemi kullanılarak, bölgeler damar içeren ve damar içermeyen bölgeler olarak ikiye ayrılmaktadır. Önerilen yöntemler arasında K-ortalamalar kümeleme tabanlı yöntem, eşikleme ve segmentasyon tabanlı yöntemleri geride bırakmaktadır.

Önerilen yöntemlerin performansı, elle ölçülmüş objektif sonuçlar ve sübjektif ölçüm olarak kabul edilebilir doktor görüşü ile karşılaştırılmaktadır. Sonuçlar önerilen yöntemlerin damar darlığı tespitinde karar aşamasında doktorlara yardımcı olabilecek güvenilir alternatifler oluşturduğunu göstermektedir. K-ortalamalar bazlı yöntem daralma bulunan damarlardaki darlık ölçümünde en iyi performansı göstermektedir. Farklı yöntemlerle hesaplanan darlık yüzdelerinin (%) ne kadar sağlıklı olduğunu ortaya çıkarabilmek için decibel olarak ölçülen, Maksimum Yüzde Hata Oranı (MPER), diye adlandırdığımız yeni bir metrik önerilmiştir. K-ortalamalar temelli yöntem MPER açısından en yüksek performansı göstermektedir.

Anahtar Kelimeler: Tıbbi İmge işleme, X-ışını anjiyografi, anjiyografi görüntüleme, bölütleme, eşikleme, K-ortalamalar kümeleme, kalp damarlarında darlık.

DEDICATION

This dissertation is dedicated to my lovely parents for their love, devoting their time to support me.

ACKNOWLEDGMENTS

I would like to thank Assoc. Prof. Dr. Hasan Demirel for his continuous support and guidance in the preparation of this thesis. Without his invaluable supervision, all my efforts could have been short-sighted.

Prof. Dr. Aykut Hocanın, Chairman of the Department of Electrical & Electronic Engineering, Eastern Mediterranean University, helped me with various issues during my studies and I am grateful to him. Besides, a number of friends had always been around to support me morally. I would like to thank them as well.

Last but not least, I would like to express my appreciation to my parents who have always given me support and encouragement would like to dedicate this study to them as an indication of their significance in this study as well as in my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATIONS

C	Number of Cluster
c_j	Center Vector
D_x	Diagonal element
d_{ij}	Euclidean distance measure
G	Segmented image, gray level of pixel
I	Identity matrix
J	Objective function
N_A	Average of gray value of A
N_B	Average of gray value of B
N	Number of cluster
R^n	N dimensional R space
T	Threshold
T_0	Initial Threshold
X	Input Dataset
X_j	Data point
x_i	Membership within i^{th} cluster
CAD	Coronary Artery Disease
CABG	Coronary Artery Bypass Graft
CCM	Cardiac Catheterization Method
FCM	Fuzzy C-Means
MPER	Maximum Percentage Error Ratio

MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
MSE	Mean Square Error
QCA	Quantitative Coronary angiography
RGB	Red, Green, Blue

Chapter 1

INTRODUCTION

1.1 Background

Research in medical databases like images is a breathtaking research area that needs an alliance among technical engineering and biomedical engineering. Recording and measurement techniques are not firstly designed to yield images like, Magneto encephalography, Electrocardiography, and others, output the data is sensitive to be shown as a time or maps versus parameter graph which include the measured positions of where we assumed it as appearances of medical imaging in a limited sense. Generally medical imaging is equivalent to radiology and the person who's responsible for interpreting the patient images is called a radiologist.

Beside medical physics and biomedical engineering, medical imaging is a field of scientific research depending on the context: Development and any research in the area of modeling, instrumentation, image acquisition and definition are usually to preserve of biomedical engineering, medical physics, and computer science. Application of the medical imaging is almost to produce the image of the internal sides of human body [1].

Basically scientists are usually seen the medical imaging as the out of inverse mathematic problems and it means inferred from effect. In the ultrasonography procedure the probe includes of ultrasonic pressure waves and echoes inside the body tissue show the internal structure and for the radiography projection, the probe is X-ray radiation which is absorbed in different tissue types such as bone, muscle and fat at different rates [2].

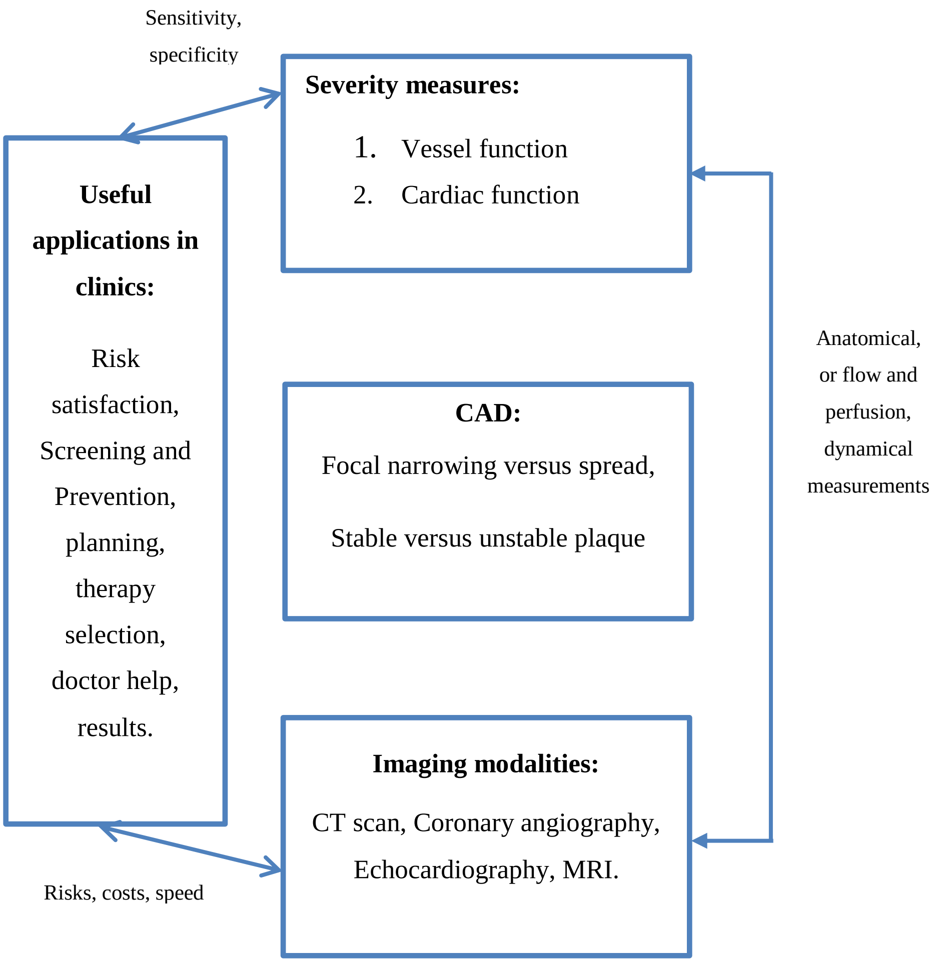


Figure 1.1: Reciprocal relationship overview among medical or clinic applications.

In Figure 1.1, a block diagram illustrating mutual relationship between clinical applications is given. You can see the way of describing the imaging modality, and evaluation of coronary artery stenosis in figure. Measurement of the evaluation of coronary artery stenosis is the central issue in this figure in a clinical setting.

1.2 Cardiac Imaging

Cardiac imaging is an indispensable gadget in determining the evaluation of coronary stenosis. In medical imaging for detection and the evaluation of coronary artery disease cardiac imaging is the method to choice and the most important reason for choosing this method is the relatively non-invasive of cardiac imaging. Even in X-ray angiography the most invasive cardiac imaging condition is to be choosing over excising a possible coronary lesion during cardiac surgery.

Employing an intravascular approach instead of surgery for non-imaging measurement methods still require cardiac imaging to set the arterial lesion [3].

1.3 Stenosis

In medical science, stenosis is a narrowing of the inner surface of the artery or valve, usually caused by atherosclerosis. Meanwhile, we have two important case of stenosis for discussion first is aortic stenosis and the second one is carotid stenosis where the doctors are normally assuming the type of stenosis for further evaluation.

- **First**, Aortic stenosis is kind of diseases which causes narrowing in the aortic valve, and it cause problem during the carry out the delivery blood from the heart to the body.
- **Second**, Carotid artery disease stenosis is kind of diseases which it cause to the narrowing of the carotid arteries, and this kind of narrowing is usually caused by the providers of fatty material and cholesterol deposits on inner surface and it called plaque. And it's important to know that carotid artery occlusion refers to complete blockage of the artery [4].

Imaging modality needs to be fast to measure cardiac function because the measurement of flow and influx requires a combination of high temporal resolutions and high spatial [5].

1.4 X-Ray Angiography

X-ray angiography is a medical imaging technique which images are taken to visualize the blood-filled areas of the body and it should be noted that these areas include various arteries or veins, which all are located throughout the body and also the chambers of the heart. The angiography is derived from the Greek words to record and for vessel. In most cases, the individual procedures needed to yield a modern angiogram for other purposes within developing a first model [6].

1.5 Heart Catheterization

In Cardiac catheterization procedure doctor's inserted a tube directly into the arteries pervasive the heart, and a substance is directly put into the blood which contrasts with the tissue of the heart. Blood flow in the vessels encompassing the heart can then easily be seen. During the catheterization process, the catheter is injected into the body at a distant site and usually the wire and the femoral artery is threaded up the arterial system to the heart where the dye is presented. This catheterization procedure is still used today and makes getting an angiography much safer as no sharp object needs to be introduced near the neither heart nor does it need to remain inside any vessel [7].

1.6 Thesis objectives

In this thesis, we propose to use three image processing methods for detection of vessels blockage in cardiac angiography images. Following the extraction of ROI, the cropped ROI goes through smoothing filter. Filter responses (smoothing) are combined and in this context the main objectives are:

- Analyzing the ROI after thresholding for the calculation of stenosis (vessel blockage).
- Applying segmentation on the thresholded pixels to be evaluated in the process of calculation of the percentage of that vessel blockage.
- Using K-means clustering method for the separation of vessel regions from the non-vessel regions for the calculation of the percentage of that vessel blockage.
- Comparing the generated results of proposed methods with doctor's opinion and manual measurement.

1.7 Thesis contributions

In this thesis, we developed and proposed three methods for the detection of stenosis of vessels in heart cardiac angiography images. This developed method includes the following three main image processing techniques:

- Image *thresholding* is used over the preprocessed vessel images, where the vessel pixels are separated from the background for further analysis to determine stenosis in percentage.
- *Segmentation* of the actual pixel values in the thresholded vessel regions is utilized for improved calculation of the stenosis.
- *K-means* clustering is used as a strong alternative to separate the vessel pixels from the background. K-means based method provides a better separation of the vessel pixels and hence the performance of the calculated stenosis is higher.
- A new metric in decibels, Maximum Percentage to Noise Ratio (MPER), is developed showing the reliability of the calculated results by reference to the manually segmented ground truth.

1.8 Thesis overview

Chapter one as an introduction that includes brief review of medical imaging and explaining main problem in cardiac images with explanation about medical background. Current methods used by the doctors for the detection of stenosis are already given; furthermore it includes description and application of x-ray angiography. Chapter two gives the definition of image segmentation, segmentation applications in medical image processing. Clustering and edge detection techniques and their relationships to segmentation are also given. Chapter three is discussing about clustering based segmentation technique and K-means clustering algorithms. In Chapter four the proposed stenosis detection methods are introduced and explained. Chapter five describes all kind of vessel and heart diseases with some clinical database. The images with stenosis go through the proposed methods and the obtained results are compared with the manually measured results and doctor's opinion. The comparison between considered methods have been observed and shown in tables and charts. Finally in chapter six we present our conclusions based on the experimental results and suggest alternative directions in future works.

Chapter 2

IMAGE SEGMENTATION

2.1 Introduction

In image processing field, segmentation requires in image analysis problems for detecting the objects and divides the image into regions such as motion, color, texture, etc. The important goal of image segmentation is to division an image into significant regions with respect to a particular application and it need to say that the segmentation is almost based on measurements which it taken from the image and might be color, grey level, texture, depth or motion and etc. [8].

2.2 Image Segmentation

Image segmentation is the one of the first step in image analysis and pattern recognition in the field of image processing and it is important and its necessary part of image analysis system, and which is one of the most difficult tasks in image processing that, determines the quality of the final result of analysis.

It should be noted that image segmentation method is the process which it divides an image into different regions and where each region is homogeneous. For more understanding we categorized Image segmentation methods as follows [9]:

1. First type is histogram thresholding and in this kind of segmentation we assumes that the images are compounded of regions with different gray

ranges, and detaches it into a number of peaks, each corresponding to one region.

2. The second type is edge-based approaches where these kinds of segmentation normally use edge detection operators such as sobel, prewitt, laplacian for example and resulting regions may not be connected so edges need to be joined.
3. The third one is region based approaches which it based on likeness of regional image data and some of the most common and widely used approaches in this category include thresholding, region growing, clustering, merging and splitting.
4. The forth one is hybrid which in this one we consider both edges and regions on image [10].

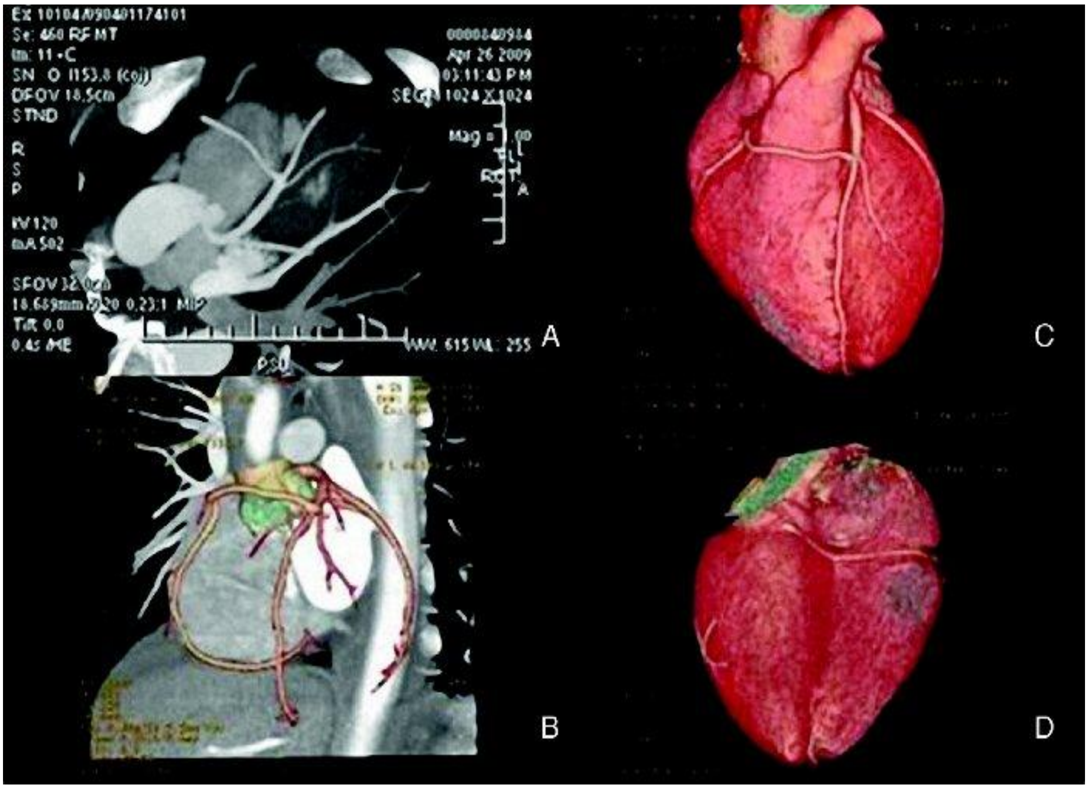


Figure 2.1: Heart Coronary vessel segmentation [11].

In Figure 2.1 you can see CT scan coronary angiography, Segmentation of coronary arteries and flow simulation for Semiautomatic and automatic segmentation of the aorta and development of where computer aided diagnosis tools for vessel wall analysis.

For processing in Figure 2.2 to remove the noise, we apply an adaptive filter, called wiener filter, while for the edges detection in both the views, a Laplacian of Gaussian filtering [2, 3] procedure is computed.

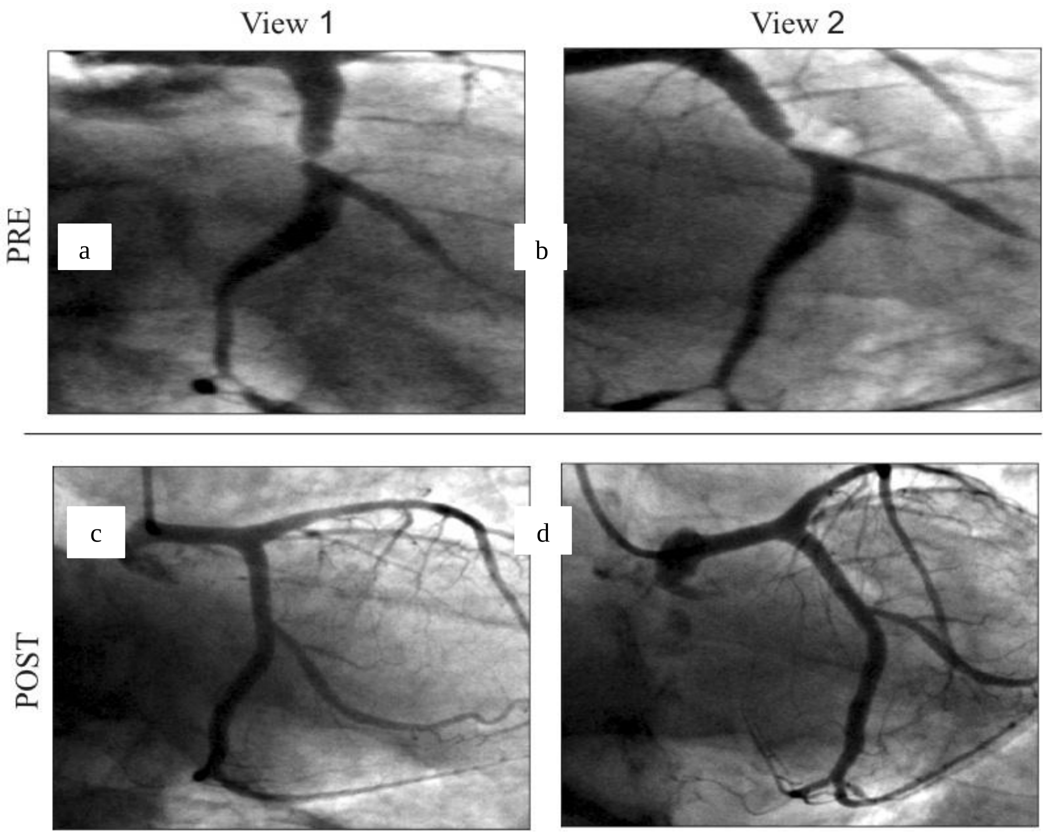


Figure 2.2: Left Coronary artery and its left marginal secondary branch before and after [12].

In Figure 2.2 where you can see Image selection of two pair of images about the left coronary artery and it’s left marginal secondary branch before (PRE) and after (POST) the surgical intervention.

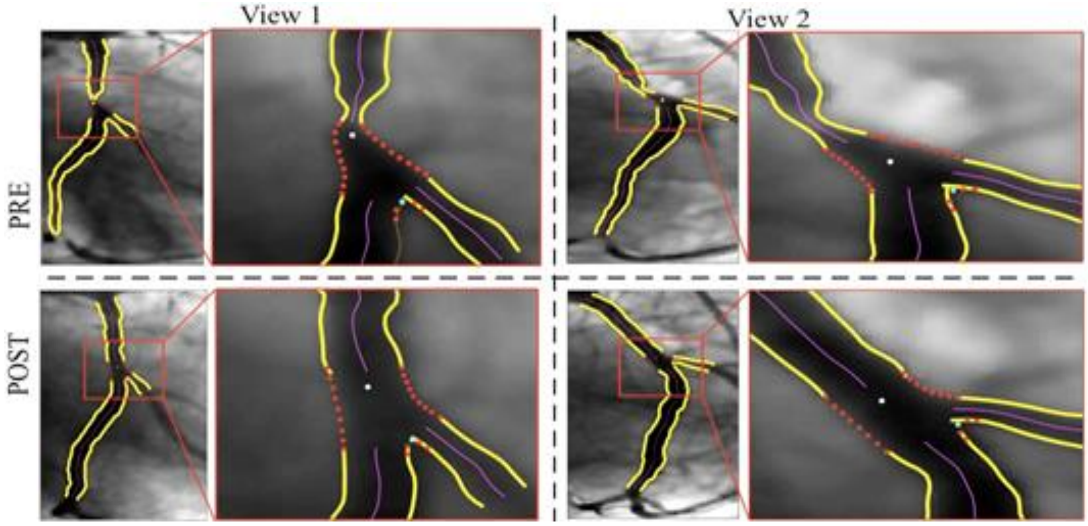


Figure 2.3: Outcome of image enhancement and segmentation procedure [13].

In Figure 2.3 obviously you can see results of the image enhancement and segmentation procedure of the two selected images before (PRE) and after (POST) the surgical intervention. The profile of the lumen contours are changed due the restoration of the lumen patency after the surgical procedure. So we can say that the result of the image processing is depicted both for the image acquired before the percutaneous coronary intervention and after the procedure to detect the success rate of the surgery, which is important in the clinical practice [14].

2.3 Image Segmentation by Clustering

Clustering can be regarded as a grading technique where given a vector of *N* measurements explaining each pixel or group of pixels in an image, a similarity of the measurement vectors and therefore their clustering in the *N*-dimensional measurement space implies similarity of the mean pixel groups or corresponding pixels. So we can say that, clustering in the case of measurement space may be a showing of similarity of image regions, and may be it can be used for segmentation purposes [15].

The vector of measurements describes some useful image feature and thus is also known as a feature vector. Similarity between pixels or image regions implies clustering in the feature space.

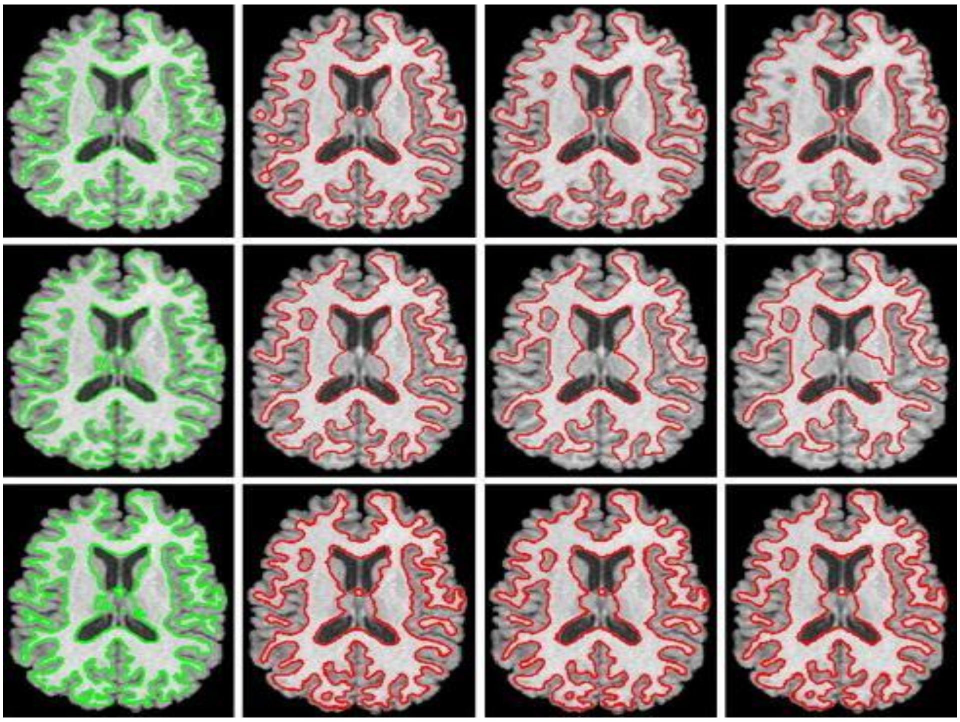


Figure 2.4: Fuzzy clustering and set segmentation on brain angiography [16].

In Figure 2.4 we can see on sample of clustering which is called fuzzy clustering by using level set segmentation integrating spatial on brain angiography.

We will discuss clearly in chapter 3 about most of the clustering techniques.

2.4 Image Segmentation by Thresholding

Technically thresholding method is the easiest method where it is one cases of image segmentation method and from any gray scale images, thresholding method can be apply to produce using histogram statistics or converting an input gray scale image to single threshold image to produce a binary image. In image processing, techniques like thresholding method is normally used to split an image into smaller segments and using at least one grayscale value or color is enough to define their boundary. A conceivable threshold image might be have 40% gray in a grayscale image it means that all pixels being darker than 40% gray belong to one segment, and others to the second segment [17].

The main difficulties associated with thresholding such as in documents occur when the associated noise process is non-stationary, correlated and non-Gaussian. Other factors complicating thresholding operation are ambient illumination, variance of gray levels within the object and the background, inadequate contrast, object shape and size non-commensurate with the scene [18].

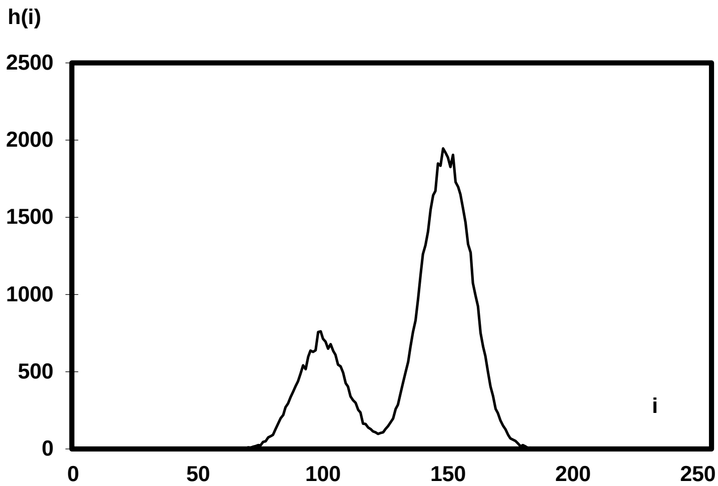


Figure 2.5: Segmentation based on histogram [19].

In Figure 2.5 we can understand segmentation based on histogram by looking at the picks of low noise object or background image. There is a clear valley between 2 peaks.

Suppose $g(x, y)$ is an image, and it has been segmented in 2 classes to applying a gray space threshold T then

$$f(x,y) = \begin{cases} 1 & if \quad g(x,y) > T \\ 0 & if \quad g(x,y) \le T \end{cases} \tag{2.1}$$

Where $f(x,y)$a 2 class's segmented image with gray scales binary is in 1 and 0 and T is referring to the threshold which it almost carried out from histogram [20].

2.5 Image Segmentation by Edge Detection

Edge detection techniques is one of the image processing techniques which basically it's convert a images to edge images using variations of gray tones in the images. As a conclusion of this change, edge image is received without having any changes in physical qualities of the original image. The purpose of segmentation is to extract favorable properties of an original image to the form of edges which they have important trait for an image to even carry the high frequency. [21].

Major difficulties in edge detection are edge localization and missing computational period with true edges. To attain excellence resolution with less noise for the image operators, the big deal is to describe suitable value to the threshold. In image processing we have three types of edges which include: 1) step edges, 2) smooth edges 3) Roof edges and each of these steps have own Property.

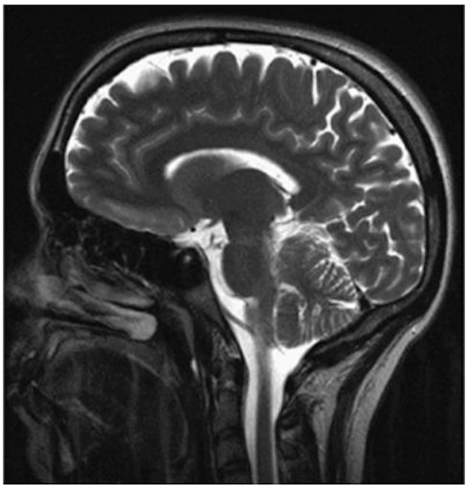


Figure 2.6: Original image [22].

Figure 2.7: Using edge detection [22].

Figure 2.6 (original brain image) scan you can see the brain bonny side and other side of it where we want to separate these two side from each other in image, in Figure 2.7 which is Magnitude of the Marr-Hildreth edge detection using the filter ask from 5×5 mask approximating an LOG, where it can be clearly seen that noise in right image is significantly enhanced [23].

Chapter 3

CLUSTERING BASED SEGMENTATION

3.1 Introduction

Clustering in image processing is the grouping together of pixels from an image, depending on calculated similarity between them. Clustering can be often defined as a non-coherent design of pixels. The color image data is naturally clustered in three-dimensional color space (RGB). All dominant colors in the image create dense clusters in the color space. Figure 3.1 provides a good illustration of the pixel clouds in RGB color space. Many color clustering techniques have been proposed in the past. Bellow, we shortly describe three classical and two less popular clustering techniques suitable for performing of color image segmentation. All these techniques are iterative [24].

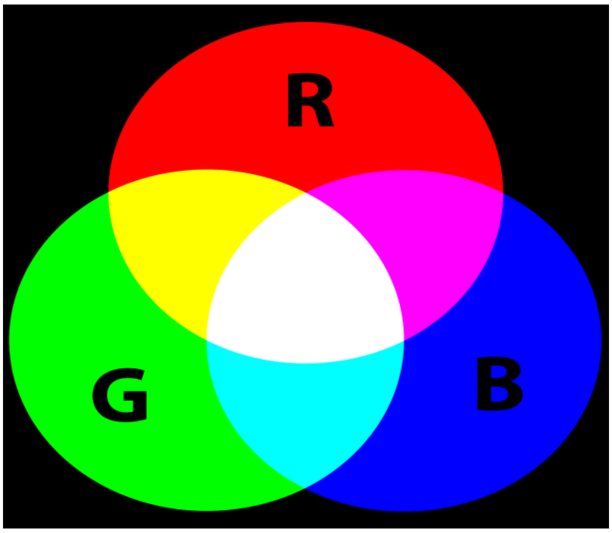


Figure 3.1: Simple Color Image [25].

In the first step of procedure a fixed number of clusters and first cluster centers in color space are picked. The main idea is the modification the positions of cluster centers so long as the sum of distances between all points of clusters and their cluster centers will be minimum. During these modifications all points areal located to closest cluster centers using a   metric.

The most typical used metrics are: the City Block metric and the Euclidean distance. After each allocation a new positions of cluster centers are computed as arithmetical means or medians. The procedure stops if the difference between new and old positions is too small. A disadvantage of k-means technique is need of initial determination the number of clusters and positions of their centers [26].

3.1.1 K-means Clustering Algorithm

Application of the K-means is to segment the image to *K* clusters and the procedure include of some steps to separate information of input image in to the absolute number of clusters. It should be noted that, in K-means techniques different locations cause different results.

For using K-means method first of all you need to get points one by one depending to the data. At the end, a primary group age appears out and it requires calculating the new *K* [27].

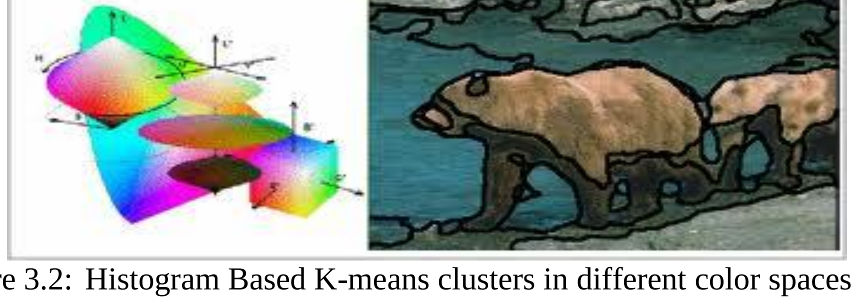


Figure 3.2: Histogram Based K-means clusters in different color spaces [28].

In Figure 3.2 you can see that when *k* becomes newer calculation has to be done between new closest and pervious data set points.

K-Means is a method to prepare a categorization of all data based on its own information and this categorization is depending on analysis between numeric values from data. So the algorithm automatically will prepare an independent categorization sans human supervision. Commonly the K-means algorithm can works with continuously samples; however it can behave like discrete data. [29].

The k-means method makes a collation between each value of the line to produce the clusters and classify the samples where the line based on distance mesures. Technically, k-means method uses the Euclidian distance to calculate how far the attribute of the pattern is from each other and how to evaluate this distance depends on how many properties exist from the provided table. After the calculation of the distances, the algorithm computes the centroid for each one of the clusters. While the algorithm goes through each step, the value of each centroid is recomputed based on the mean of the values of each attribute of each pattern that belongs to this centroid. Thus, the algorithm results with k centroids and put the patterns of the table in accordance to its distance of centroids [30].

I will present K-means process at the following steps to show that how the algorithm works

- **Step 1**: start with a decision on the value of k like taking the first k samples of the table and dedicate each of remaining (*N*-*k*) samples to the cluster.
- **Step 2**: Create a distance matrix between each the centroids and pattern where difficulty of this step is the heavy calculation, it means that when we

have N samples and k centroids then the algorithm will have to evaluate $N \times K$ distances.

- **Step 3**: Put each sample in the cluster with the nearest centroid and if the sample is not in the cluster with the closest centroid, then switch this sample to that cluster.
- **Step 4**: Update the new *k* centroids for each cluster where the updated location will be a centroid.
- **Step 5**: Repeat until the isotropy condition satisfied [31].

In Figure 3.3 shows the all explained steps in the form of diagram.

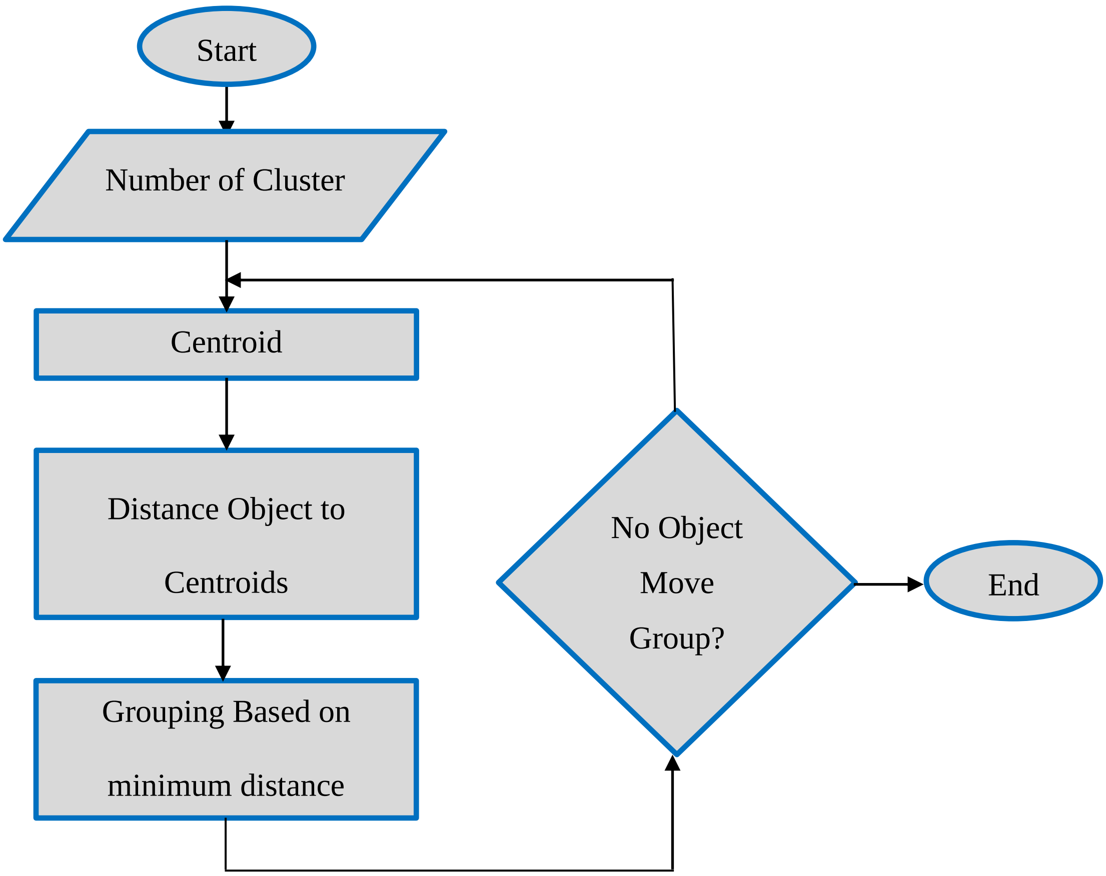


Figure 3.3: Block diagram of K-means process [32].

3.1.2 Clustering Process

- **Step 1**: Input image is taken in the form of pixels then transformed in the form of RGB.
- **Step 2**: Similar data are grouped together like point which has same color and information with using clustering method like K-means method where you can see in the chart.

Following block diagram in Figure 3.4 shows a typical clustering process in segmentation:

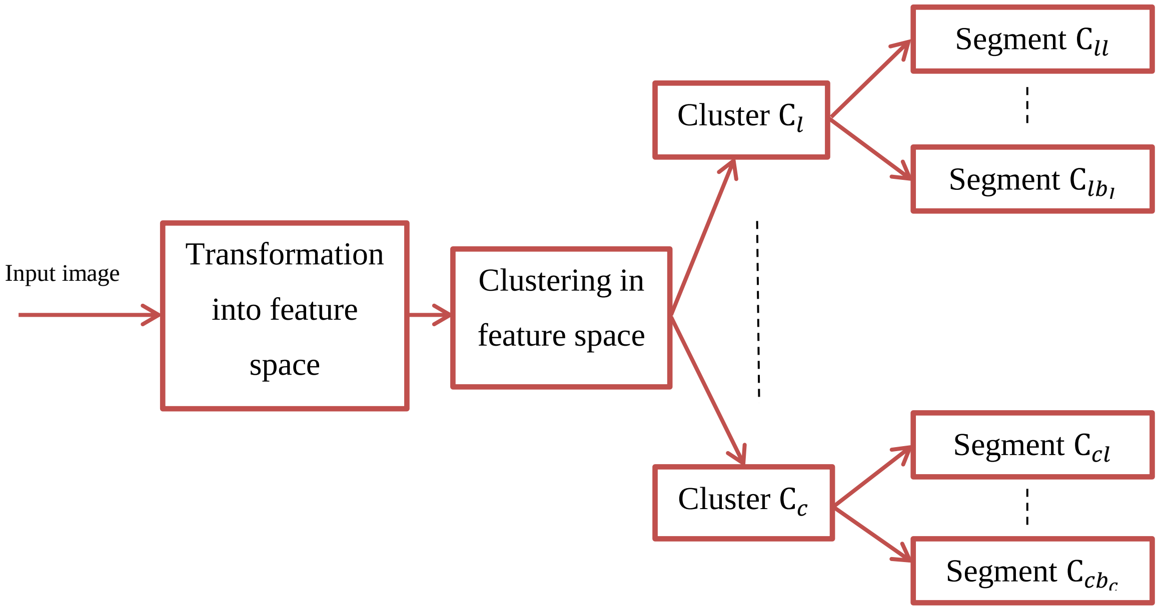


Figure 3.4: Flow-chart of an image segmentation method.

Figures 3.5 shows and example of original input image and the respective segmented images where in Figure 3.6(a) image segmented with 4 clusters and in Figure 3.6(b) image segmented with 6 clusters.

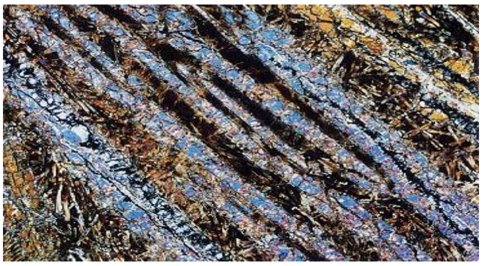


Figure 3.5: Original Image [33]

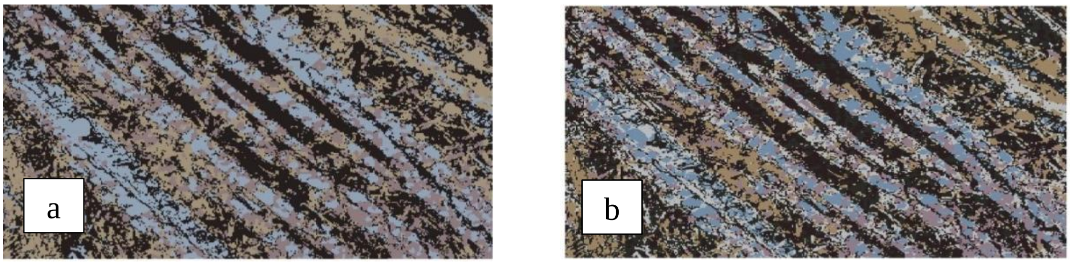


Figure 3.6: a) Image segmented with 4 clusters, b) Segmented with 6 clusters [33].

Chapter 4

PROPOSED STENOSIS DETECTION TECHNIQUES

4.1 Introduction

A new image processing procedure enabling the semi-automatic detection and measurement of coronary artery stenosis by using angiography images is proposed by using computer image processing techniques in the following pre and post processing.

Pre-processing:

- Manually drawing the Line of interest (LOI) through the vessel blockage.
- Region of interest (ROI) is extracted around LOI after normalization.
- Gaussian low pass filter is used to provide smoothing in ROI.

Post-processing:

- Method 1: Thresholding method is used on filtered image.
- Method 2: Segmentation method is used by multiplying the filtered image and thresholded image.
- Method 3: K-Means method is used on filtered image.

These three methods facilitate the detection of stenotic lesions from coronary angiograms.

4.2 Step by Step Description of the Pre-Processing

In this part we describe each part of the pre-processing procedure which is applied at the initial stage of the proposed methods.

The pre-processing involves the following 3 steps:

- **Firstly**, after visual inspection, the section of the vessel which is to be analyzed for stenosis measurement is selected by drawing a LOI between the two points chosen. The two points are centered at narrowest side of clogged vessel, and we need to keep distance before and after clogged part with normal size of vessel.
- **Secondly**, after rotation normalization, region of interest (ROI) containing clogged part of the vessel is extracted by cropping.
- **Thirdly**, the extracted region of interest which corresponds to a small section of the entire image, needs smoothing to get rid of embedded noise and blocky artifacts. This process is important, since the quality and resolution can affect further processing.

The proposed methods a common pre-processing process stated above and 3 different post processing. In summary, in the pre-processing the following steps are taken:

- Line of Interest (LOI).
- Region of Interest (ROI).
- Gaussian Smoothing filter.

Figure 5.1 shows the system diagram for pre-processing.

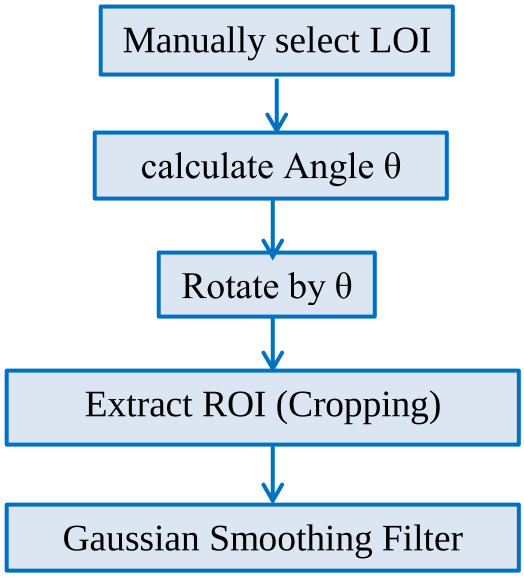


Figure 4.1: Pre-processing System diagram.

4.2.1 Line of Interest (LOI)

The process starts by drawing a line of interest (LOI) on blocked area of the vessel. LOI is important, since is forms a foundation to the extraction of the region interest in the next stage. Selection of LOI helps us to focus exactly on blocked area to find the suitable location for stenosis detection. It is important that two sides of selected points for LOI to be approximately the same distance from the center of the line.

Once image displayed and appears on your screen, you the graphical user interface of the program allow you to draw a line through the blocked vessel by locating two points using mouse. While carrying out this procedure, it is important to have the midpoint of the blockage of the vessel to be around the center of the LOI.

You can see on Figures 5.2 where we start by clicking from right side. It is recommended to start this procedure by ascertaining the direction of blood flow then start drawing from that point, nevertheless keep in mind that images vary so you need to ascertain direction of blood flow.

Let $P_1(x, y)$ and $P_2(x, y)$, to be the begining and ending points of selected LOI. In Figure 5.2 you can see line $P_1(x, y)$ on vessel.

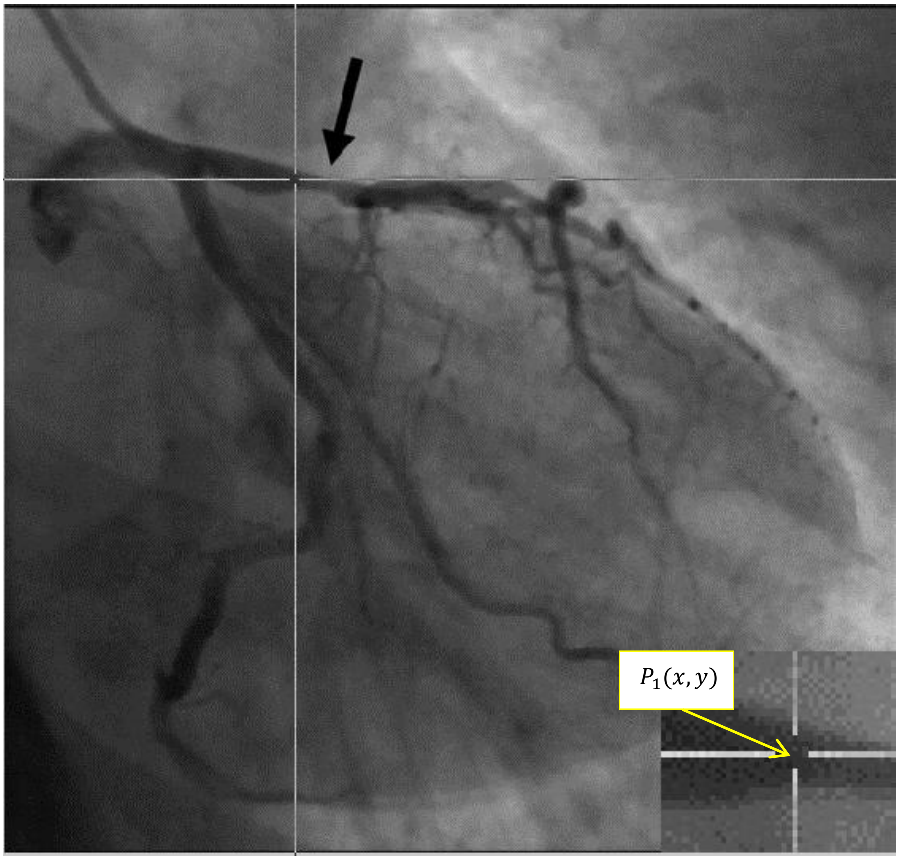


Figure 4.2: Starting point for LOI.

So if we look clearly at Figure 5.2 the P_1 shows the starting point on mid part between blockage point and normal size of the vessel, thus we need to draw as the same form on the side of the blockage point.

So for selecting the second point on the blockage vessel as we described before, we consider the mid diameter of normal side of vessel then click that point to get figure, and you can see in Figure 5.3 how $P_2(x, y)$ is selected.

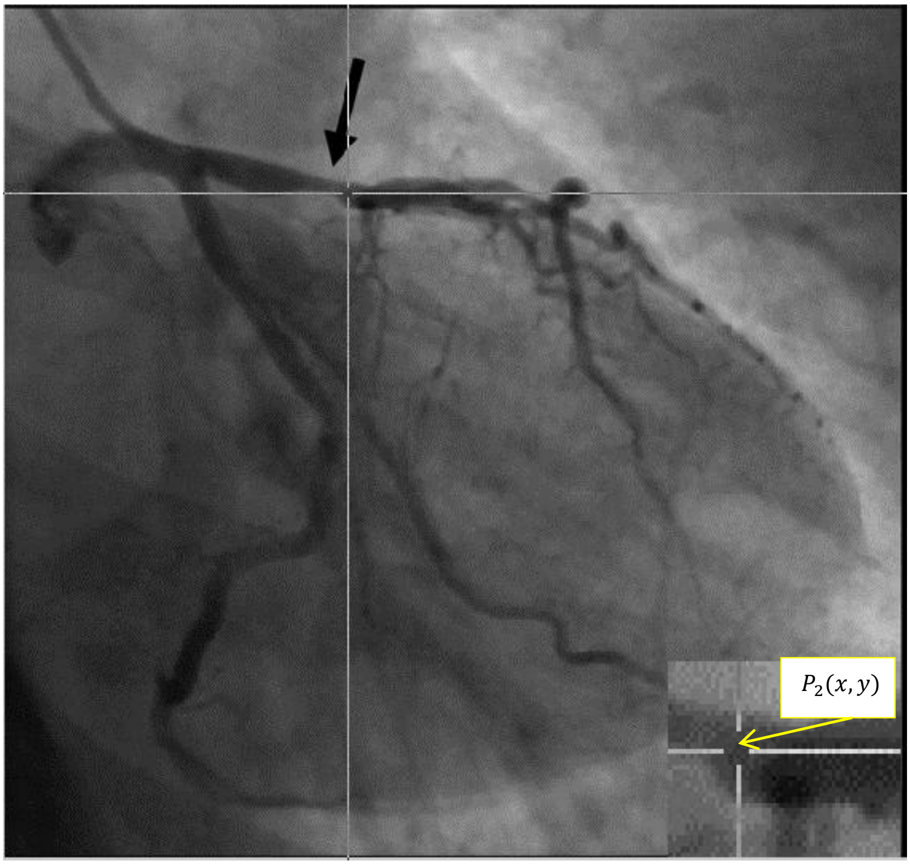


Figure 4.3: Ending point for LOI.

4.2.2 Region of Interest (ROI)

After selecting LOI, we semi-automatically draw our rectangular box around the LOI. A rectangle is automatically drawn by assuming that $P_1(x, y)$ and $P_2(x, y)$ are the left upper and right lower corners of the rectangle respectively. We can see in Figure 5.4, the captured image shows selecting semi-automatically region of interest in actual size, the black arrow shows the exact clogged area.

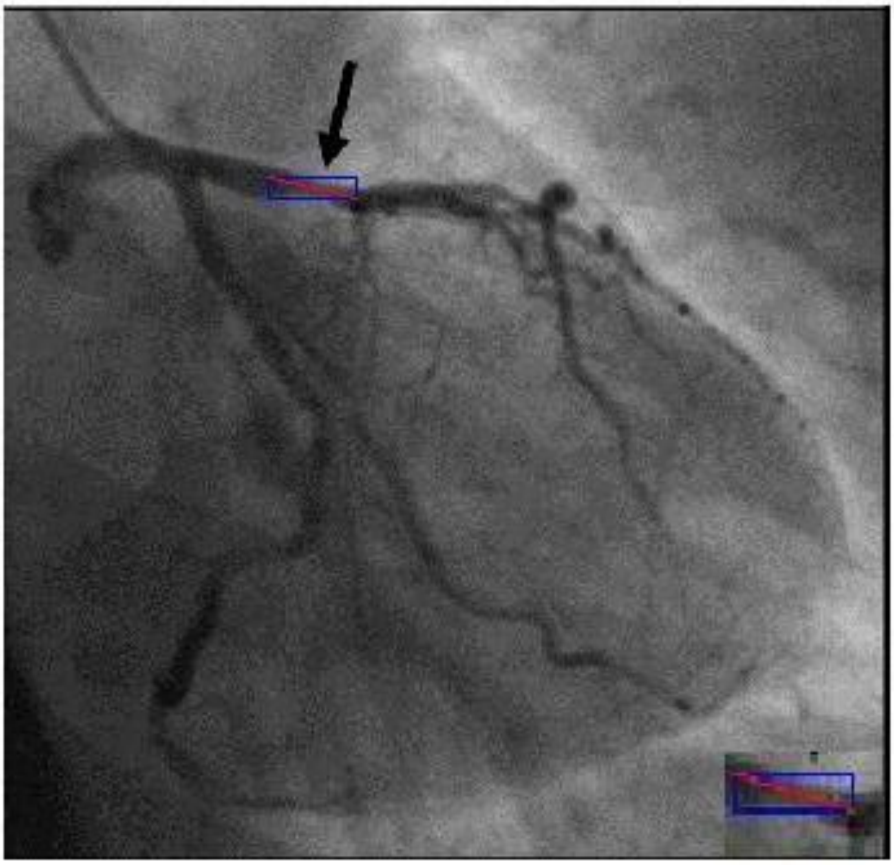


Figure 4.4: Capturing Region of Interest and Line of Interest together.

4.2.3 Rotation Normalization

After extracting the LOI and a rectangle around it, we calculate the angle that would rotate the LOI to be rotationally normalized, where the LOI becomes horizontally oriented. The angle of the required rotation, Θ, can be calculated as follows:

$$\Theta = tan^{-1}\frac{y_2-y_1}{x_2-x_1} \tag{5.1}$$

Where:

y_2 = Vertical Position of $P_2(x, y)$

y_1= Vertical Position of $P_1(x, y)$

x_2= Horizontal Position of $P_2(x, y)$

x_1= Horizontal Position of $P_1(x, y)$

In Figure 5.5 we can see the normalized angio image with LOI in horizontal orientation.

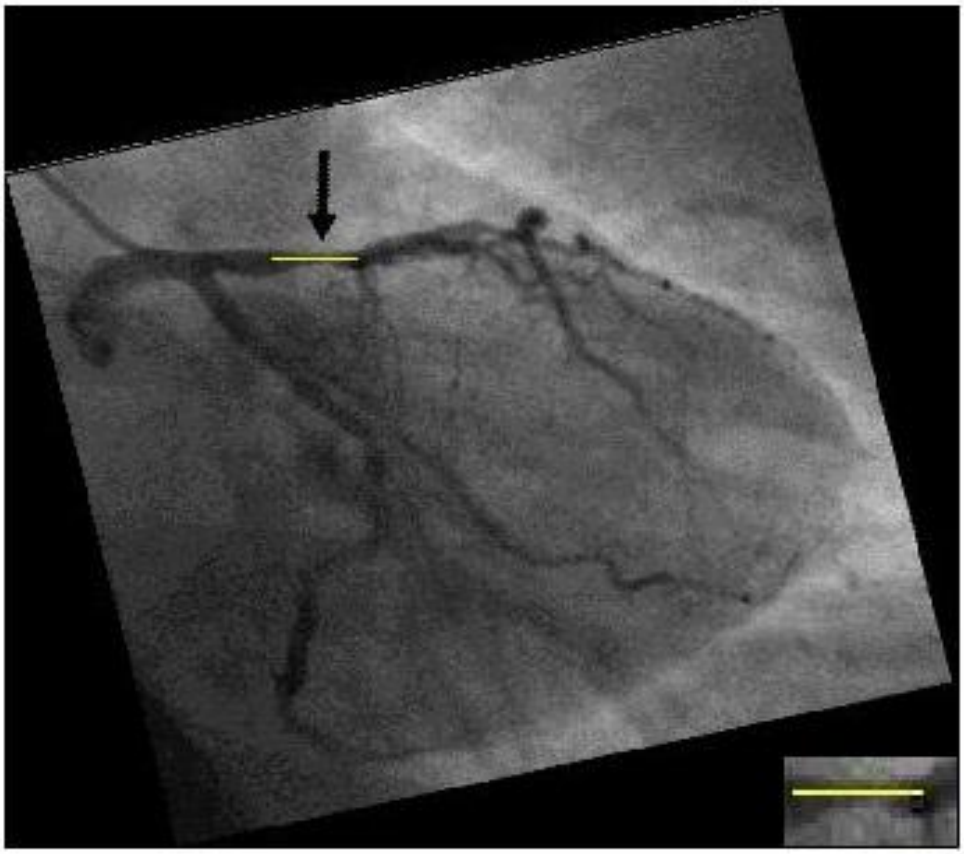


Figure 4.5: Rotationally Normalized LOI.

4.2.4 Cropping the ROI

Rotation normalization is followed by cropping a rectangle around the LOI which approximately centers the clogged vessel that we need to analyze. This rectangular region, which we refer to as the region of interest (ROI) contains the vessel image that we will use in the post-processing. The width of the rectangle is equal to the width of the LOI and the height is chosen such that it encapsulates the vessel that is being studied. The following steps are undertaken in the process of cropping ROI:

- After normalization crop the ROI by using an area above and below of LOI such that the size of the cropped region in $n \times m$ pixels where n is the length of LOI in pixels and m is selected to be 30 pixels.

Figure 5.6 illustrates the LOI and the cropped ROI at the right bottom of the image.

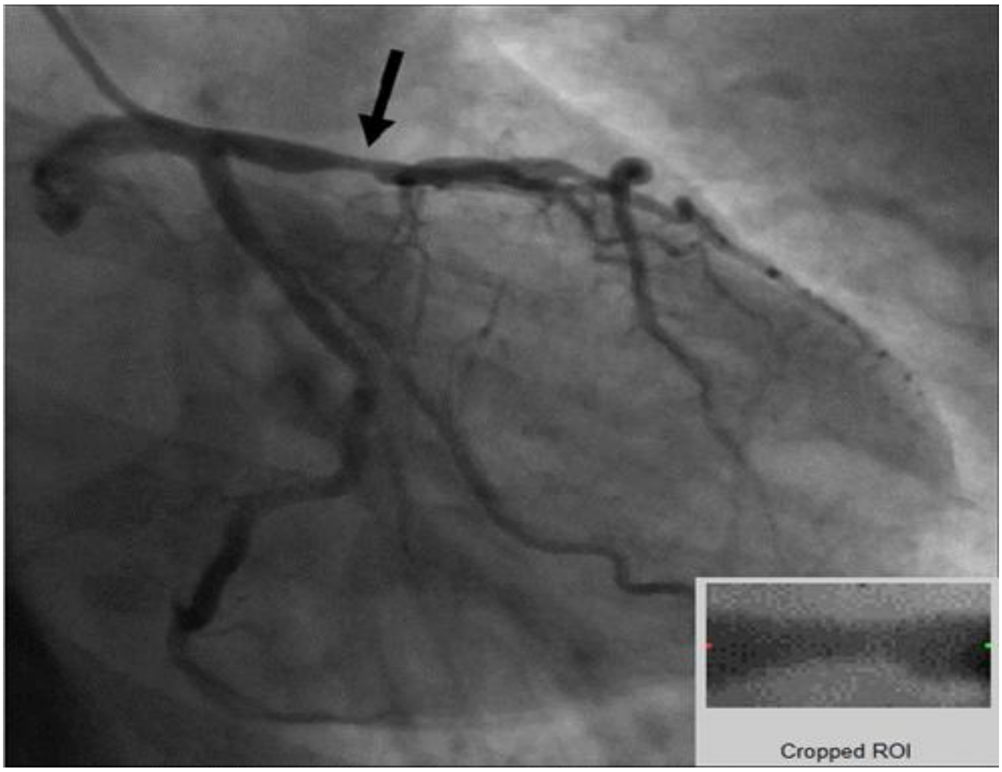


Figure 4.6: Angio image analyzed and the cropped ROI.

4.2.5 Smoothing - Gaussian filtering

Gaussian smoothing filter has an impulse response as the Gaussian function. The filtering process is a convolution by the surface image and filter image.

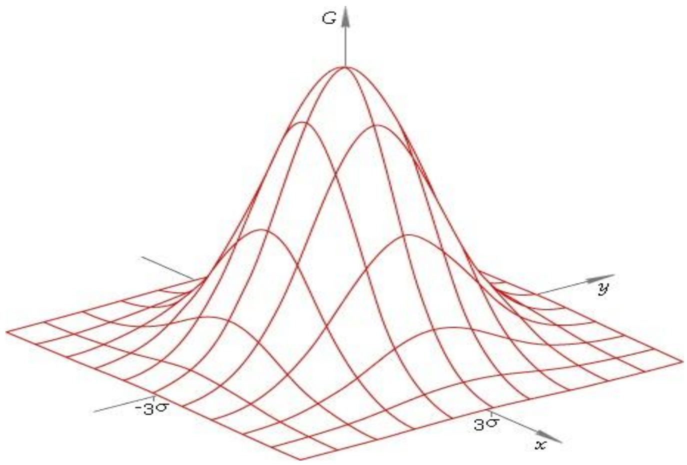


Figure 4.7: Gaussian filter in 2D.

The impulse response of 1-D Gaussian filter given by

$$f(x) = \sqrt{\frac{a}{\pi}}\, e^{-ax^2} \qquad (5.1)$$

Frequency response is also given by

$$\hat{f}(g) = e^{-\frac{\pi^2 f^2}{a}} \qquad (5.2)$$

So the equations also can be represented with standard deviation as parameter

$$f(x) = \frac{1}{\sqrt{2\pi}\,.\,\delta}\, e^{-\frac{x^2}{2\delta^2}} \qquad (5.3)$$

Also frequency response is given by

$$\hat{f}(g) = e^{-\frac{f^2}{2\delta_f^2}} \qquad (5.4)$$

So with writing a in the function form of δ_g and almost with two equations for $\hat{f}$ (g) and in the function form of δ including two equations for *f(x)* it shown that as the result of the standard deviation in the frequency domain and for standard deviation is given by

$$\delta.\delta_g = \frac{1}{2\pi} \qquad (5.5)$$

In above equation the form of standard deviations is represented in their own physical units where the time is referred in seconds and frequency in hertz.

In 2D form Gaussians the result

$$f(x,y) = \frac{1}{2\pi\delta^2} e^{-\frac{x^2+y^2}{2\delta^2}} \qquad (5.6)$$

It needs to be explained that, y is the distance from origin in the vertical axis and x is the distance from origin in the horizontal axis, and δ is the standard deviation of the Gaussian distribution [34].

After understanding the concept of Gaussian-smoothing filter we can apply this filter on our cropped image, since the cropped image has noise and blocky artifacts.

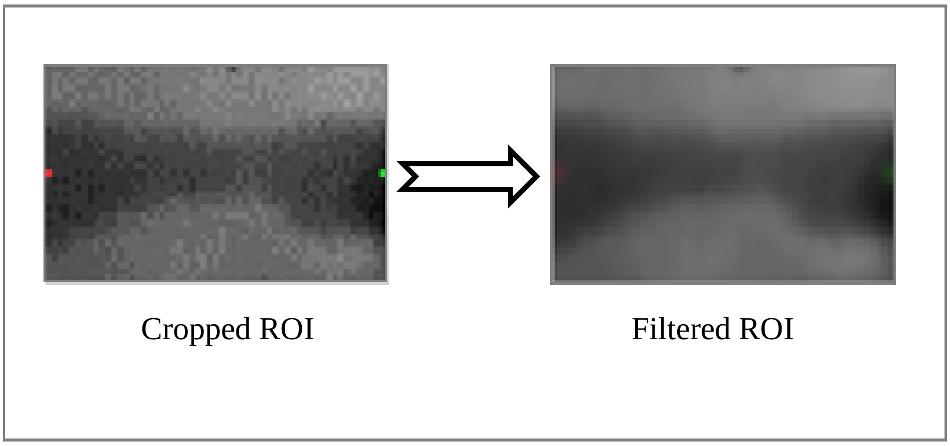


Figure 4.8: Before and after Smoothing filter.

In Figure 5.8 you can see the differences between before and after Gaussian filtering. In filtered image we can better separate the vessel from image.

After completing the pre-processing we can introduce the following three post-processing approaches to be used within the proposed methods. In the post processing the following approaches are utilized:

- Thresholding
- Segmentation
- K-Means Clustering

4.2.6 Proposed Thresholding Method

Basically thresholding method is kind of the methods where it approaches generally used in segmentation methods.

- Thresholding method is one of the most important approaches for image segmentation.
- In thresholding method, totally pixels are alike grouped together and even in the form of gray scale.

- Thresholding can be seen as an function that involves tests versus a function T of the form

$$T = T[x, y, (p(x, y), f(x, y)] \qquad (5.7)$$

- Where *p(x, y)* refers some property of the point such as *f(x, y)* is the gray level at the point *(x, y)* and the average gray level of a neighborhood centered *on (x, y)* [35].
- Threshold image is defined as

$$g(x, y) = \begin{cases} 1 \ if \ f(x, y) > T \\ 0 \ if \ f(x, y) \le T \end{cases} \qquad (5.8)$$

In above equation the pixels labeled as 1 correspond to objects, and the pixels labeled as 0 correspond to the background [36].

We start to apply thresholding technique on our system and basically we can perform thresholding based on the mean of the pixels in the ROI. Complete block diagram of the thresholding method is given in Figure 5.9 below.

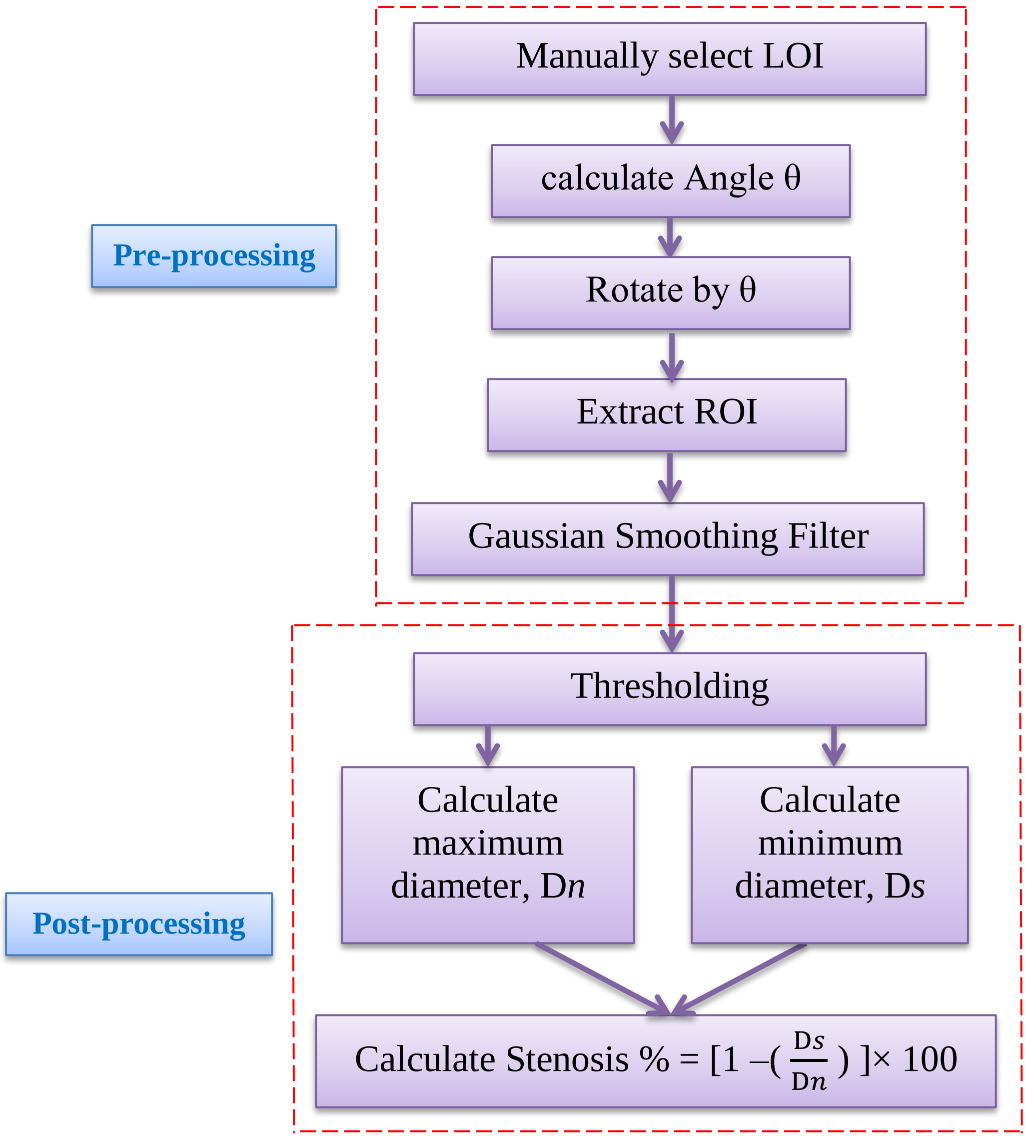


Figure 4.9: Proposed thresholding system diagram.

In Figure 5.9, first we need to select our line of interest then after that our region of interest (ROI) will appear automatically, for better vision we do some smoothing filter on cropped image where it is selected from region of interest, so for further processing of diagram it is obvious that how thresholding method can apply. Remember that the important part for evaluation of stenosis by thresholding method to find with thresholding based on all region of interest, because we need to calculate number of black pixel where it is located inside of vessel and it necessary that the black part never mix with the white side of region of interest because it will give a wrong percentage of blockage in this method. In the final part of system diagram you can see the formula where it shows that how a mathematical and standard formula will do calculation of stenosis according to the vessel diameter.

D*s* is the diameter of the stenosis portion of the lesion, it is important to also need to be careful about line of interest to passed from inside of blocked area, this corresponds to the minimum in middle area of the ROI.

D*n* is normal vessel diameter where this one needs to be selected in the mid part of normal sized vessel.

In Figure 5.10 you can see the image showing the effect of thresholding method.

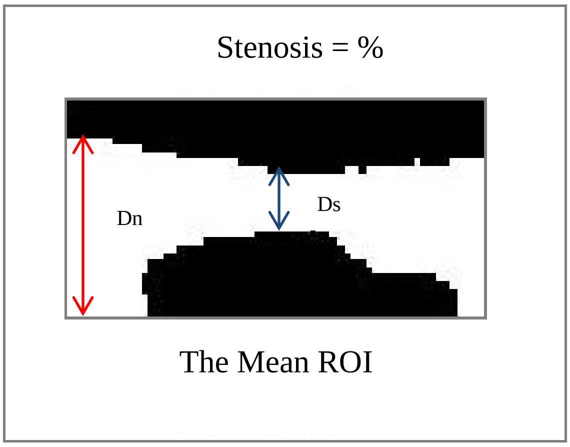


Figure 4.10: Thresholded cropped and smoothed image.

4.2.7 Proposed Segmentation Method

In our last method for evaluating a percentage of blocked artery and according to the method it is obvious that the results are almost better than both thresholding and doctor evaluation method, however it is not good enough as clustering (K-Means) method so it can be our second choices for detection.

For clearly understanding we start to explain with our block diagram:

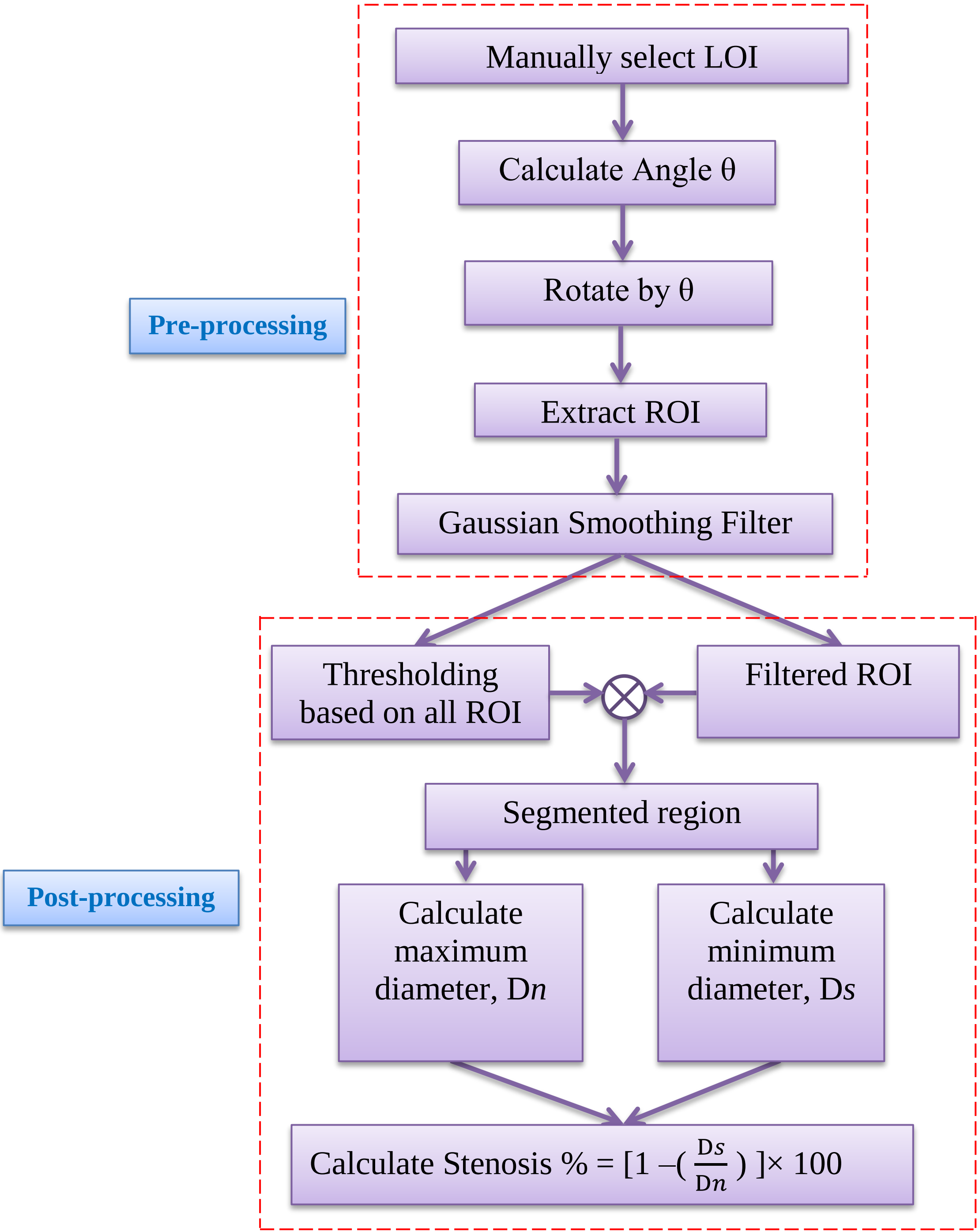


Figure 4.11: Segmentation method system diagram.

It is obvious that in Figure 5.14 first we should select our line of interest then after selecting line of interest our region of interest will come after that, and for better vision we did some smoothing filter on cropped image which it selected from region of interest, and for further processing of diagram we can see how segmentation method can apply. For obtaining a segmented image we did multiplication for filtered image with threshold image, however in filtered image we don’t have much noises, but we some unwanted region and for omission of that region we can multiply to the threshold image. For the final part of system diagram you see the formula which it is marker a mathematical and standard calculation of stenosis according to the vessel diameter.

Ds is the diameter of the stenosis portion of the lesion, it is important to also need to be careful about line of interest to passed from inside of blocked area.

D*n* is normal vessel diameter where this one needs to select in the mid part of normal sized vessel.

In Figure 5.15 you see the image showing the effect of segmentation method after applying, and it is pretty obvious that we don’t have much unwanted area in image, so it can be change a little amount of percentage for our system calculation to obtain the closest percentage of stenosis according to the manual method for further discussion.

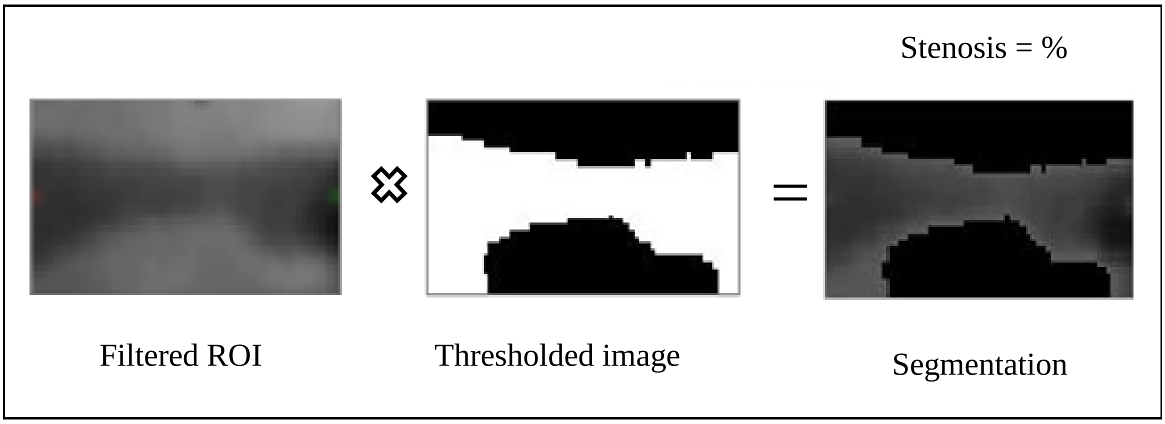


Figure 4.12: Segmented image process.

4.2.8 Proposed Clustering (K-means) based Method

K-means (clustering) method is a repeated technique that is used to division an image into K clusters, and the basic algorithm follows by

- Pick randomly or based on some exploratory, *K* cluster centers
- Assign each pixel in the image to the cluster for minimizing the distance between the pixel and the cluster center.
- By averaging all of the pixels in the cluster re-compute the cluster centers

In this situation, distance is the absolute difference or squared between a cluster center and a pixel.

The actual difference is typically based on intensity, pixel color, location, and texture, or a weighted combination of these factors.

The above algorithm is guaranteed to converge, but it may not return the optimal solution. The quality of the solution depends on the value of *K* and the initial set of clusters [37]. The number of clusters used in this method is chosen to be 4. This is because 2 darker clusters correspond to blood vessel and the 2 lighter clusters correspond to non-blood vessels.

So for our clustering part we assumed darkness side of clustered image as D*n* and brightest of the clustered image as a D*s*, and you need know that all part of the discussion such drawing line of interest until smoothing is same procedure as previous part. So we can see all part of a discussion in system diagram for clustering method.

The Figure 5.11 is the process as the same as thresholding part, however until smoothing.

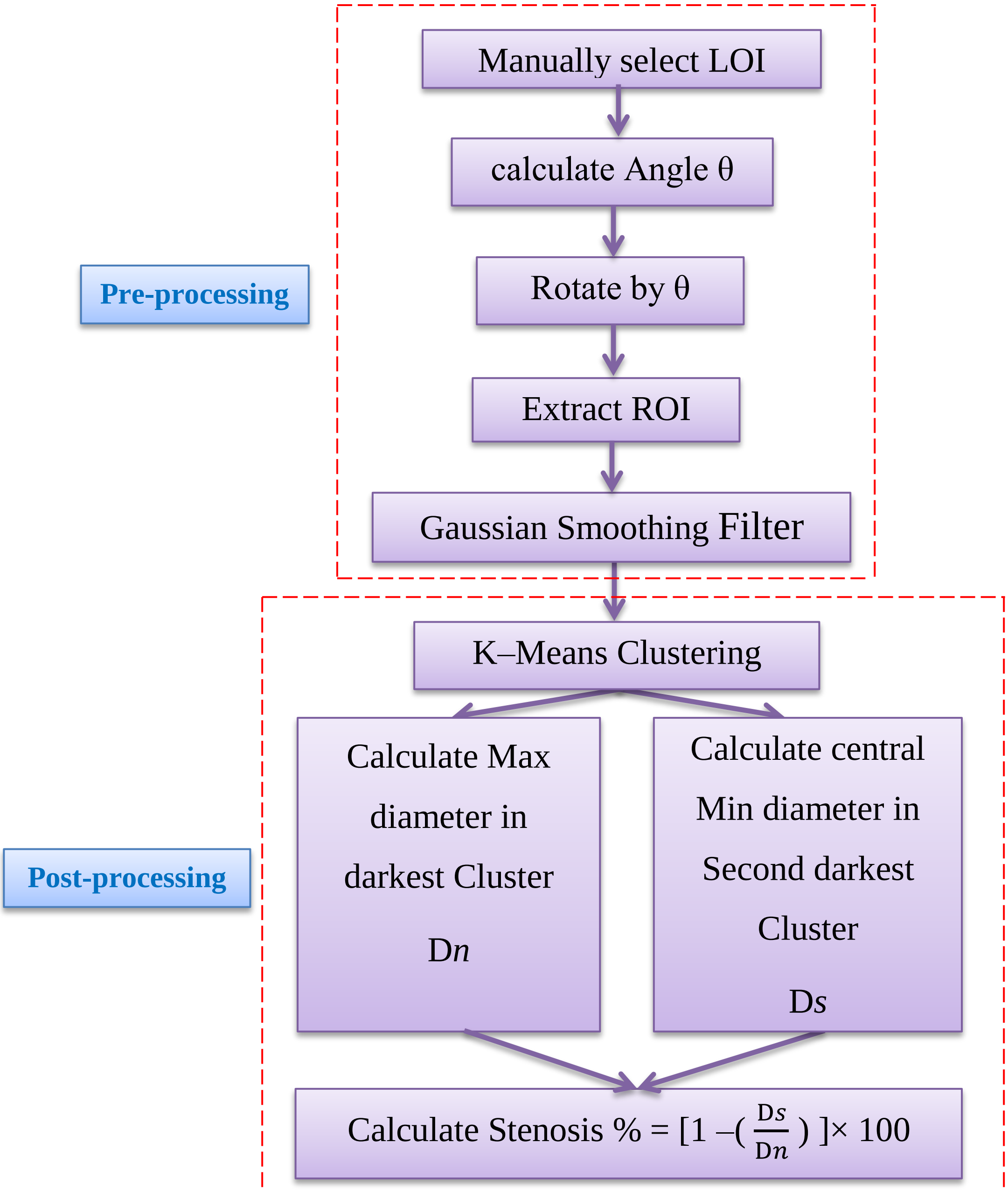


Figure 4.13: K-means clustering method system diagram.

In Clustering section for our system evaluation of stenosis we start with 1st cluster which corresponds to very clear blood vessel pixels. 2nd cluster corresponds to second darkest pixels where stenosis is affecting the tone of the respective pixels.

In Figure 5.12 you can see the cluster 1 and cluster 2 on cropped ROI, where in both images there is some unwanted regions which can cause effect on system stenosis evaluation according to the manual method.

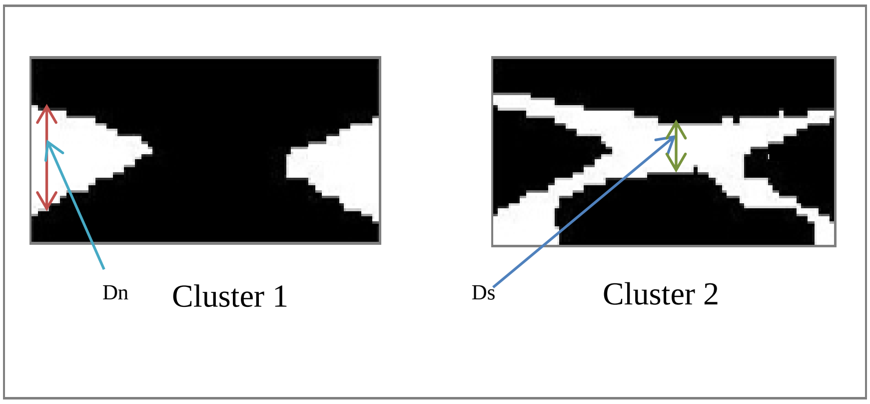


Figure 4.14: Cluster 1 and cluster 2 of the sample ROI.

In Figure 5.13 we used 4 cluster on image, you can see 4 clustered image with filtered image, which it shows vessel and heart and this shows that we can separate the vessel part from heart muscle when the catheter is injected.

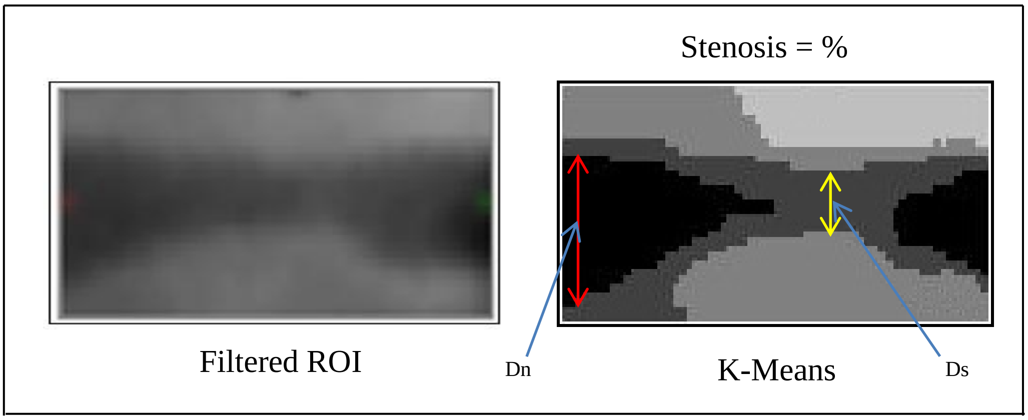


Figure 4.15: 4 Clusters obtained by K-means.

D*s* is the diameter of the stenosis portion of the lesion, it is important to also need to be careful about line of interest to passed from inside of blocked area.

D*n* is normal vessel diameter where this one needs to select in the mid part of normal sized vessel.

4.2.9 Stenosis Analysis

In Figure 5.16 you see whole system, where we see our proposed system with all of evaluation cases with methods differences.

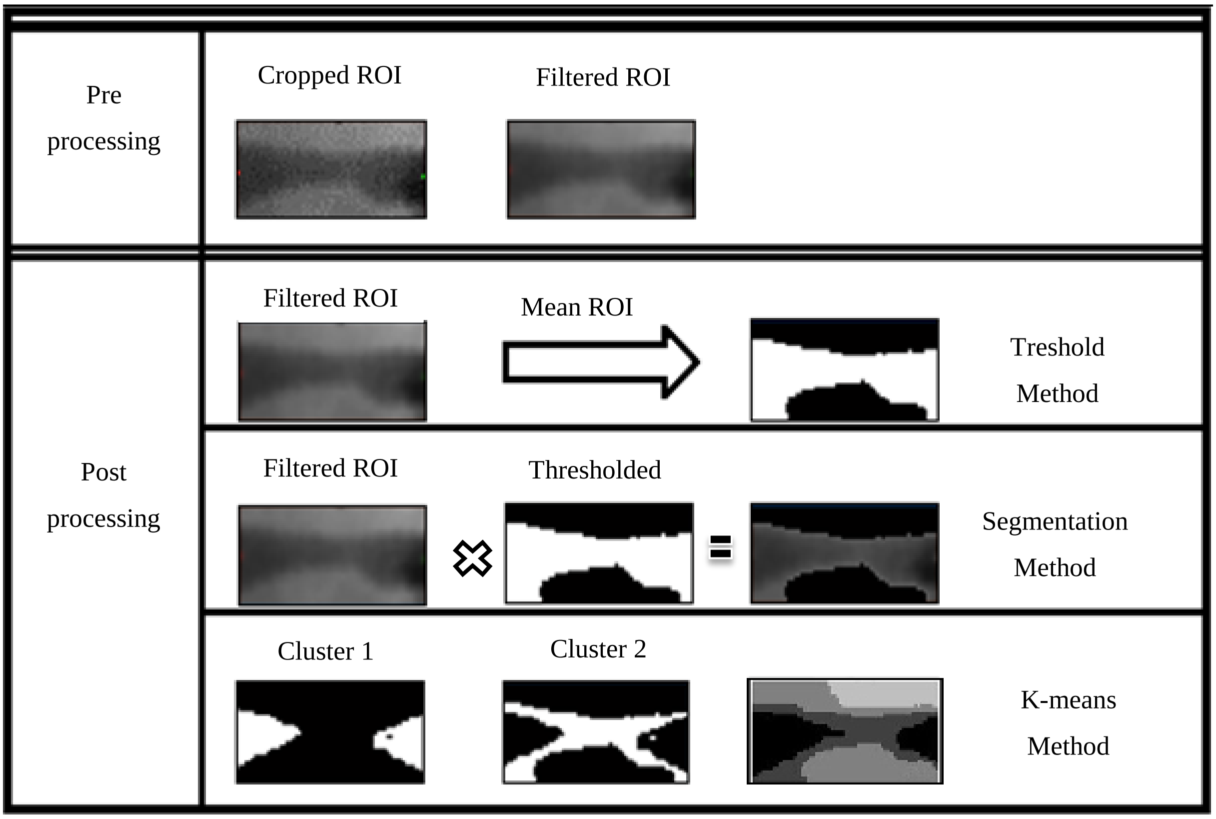


Figure 4.16: Complete evaluation system using 3 different methods.

Where for evaluating the percentage of stenosis we use standard mathematical formula our system and we can describe it like this

(5.9)

$$\text{Stenosis Percentage} = [1 - \left(\frac{\mathrm{D}s_2}{\mathrm{D}s_1}\right)] \times 100$$

D*s* is the diameter of the stenosis portion of the lesion, it is important to also need to be careful about line of interest to passed from inside of blocked area.

D*n* is normal vessel diameter where this one needs to select in the mid part of normal sized vessel.

4.3 Standard (Manual) Method

In this part we explain the standard method and we give one of our examples to show how we calculate the stenosis percentage in standard method. And all procedure of measurement requires working on matlab imtool window.

For calculating the standard method we need to first find the blockage area and then start to zoom on that part and also we must find the normal diameter of vessel for measurement, after that the important case is to start measure the stenosis lesion and this part of vessel must less than normal diameter, if the size for both of them are become equal, then we don’t have any stenosis.

In Figure 5.13 you can see that we start to open figure in matlab imtool window.

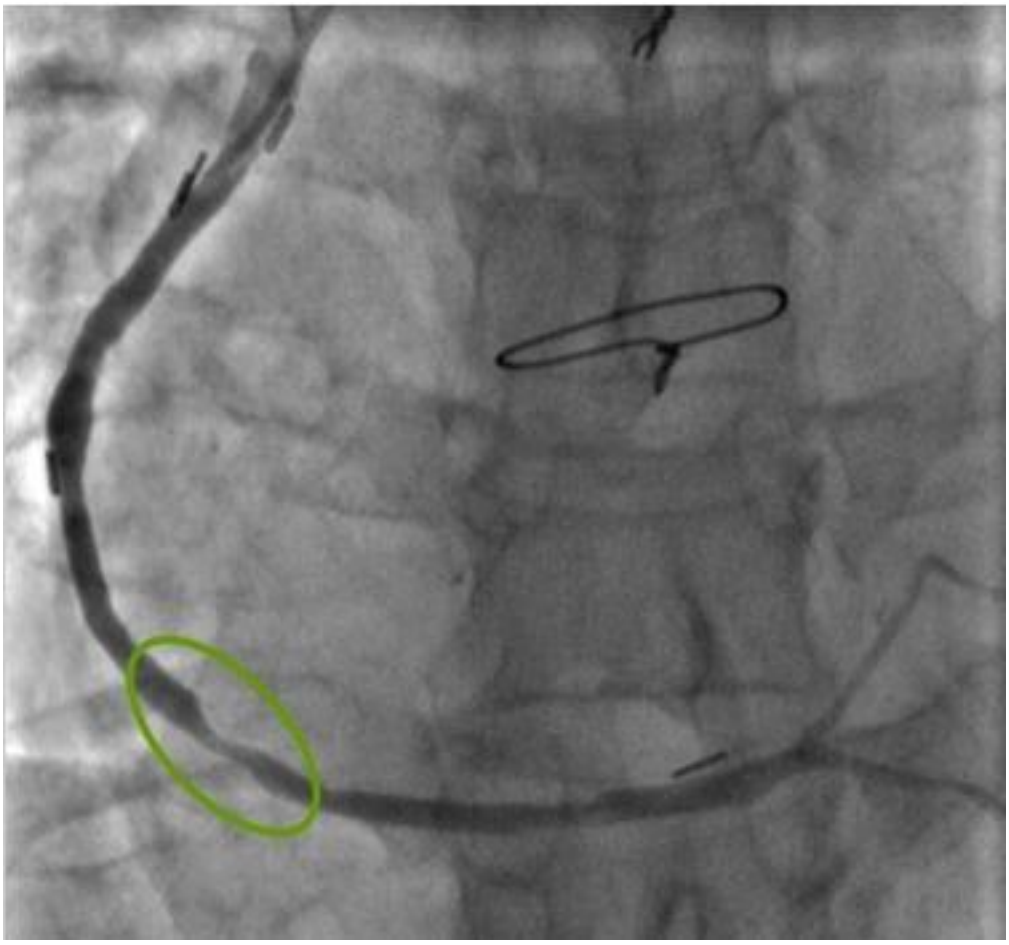


Figure 4.17: Input example for manual measurement.

In Figure 5.13 even you can see the exact area coordinate for special measurement, and also you can see that the blocked area is pointed with green circle.

So we start our measurement by normal diameter side, so in figure 5.14 you can see the initial measurement, meanwhile you need to select measure distance from matlab tools.

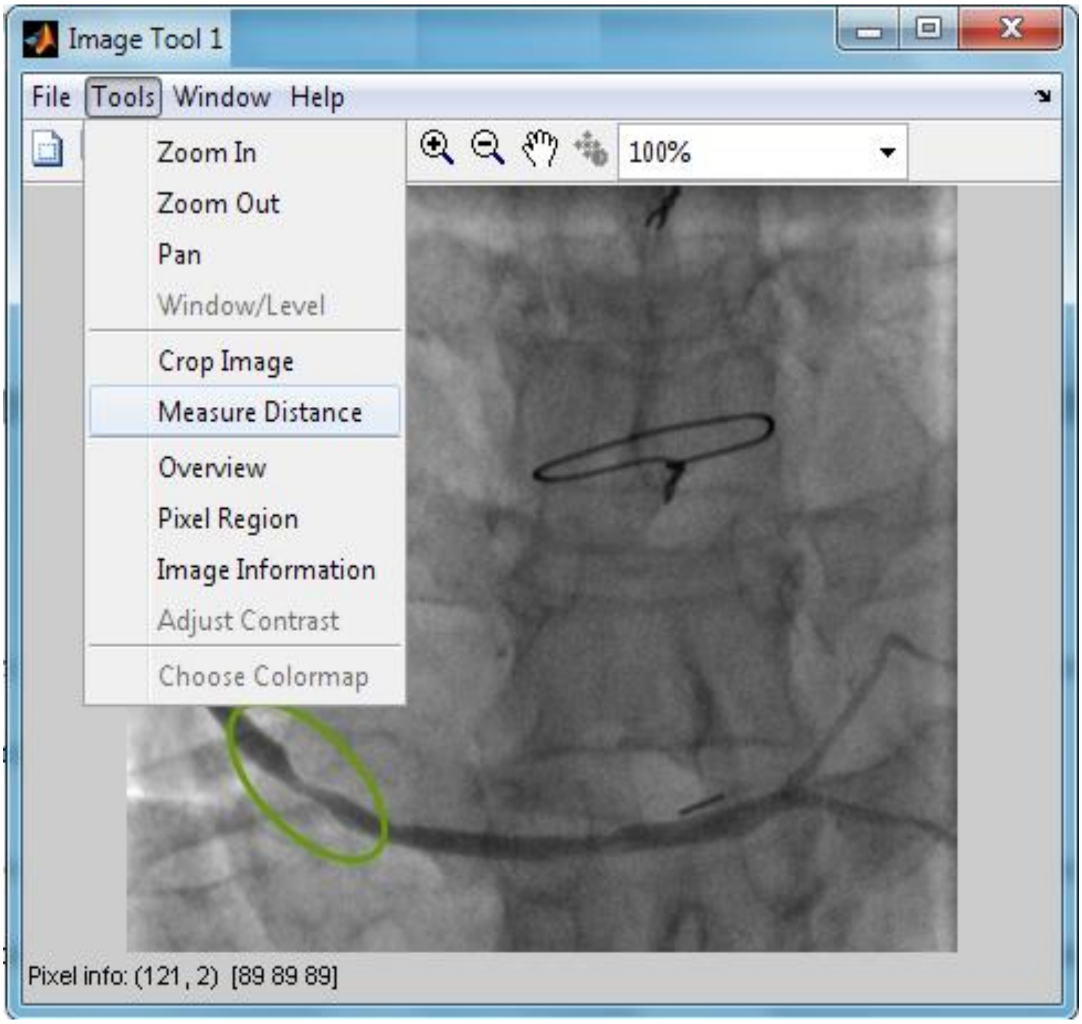


Figure 4.18: Distance selection from malab tools.

For second step we should zoom from tools and start to zoom on the blocked area and start to click for drawing on normal diameter vessel.

In Figure 5.15 you can see the clicking point for normal side of the normal inside and get size of D*n*:

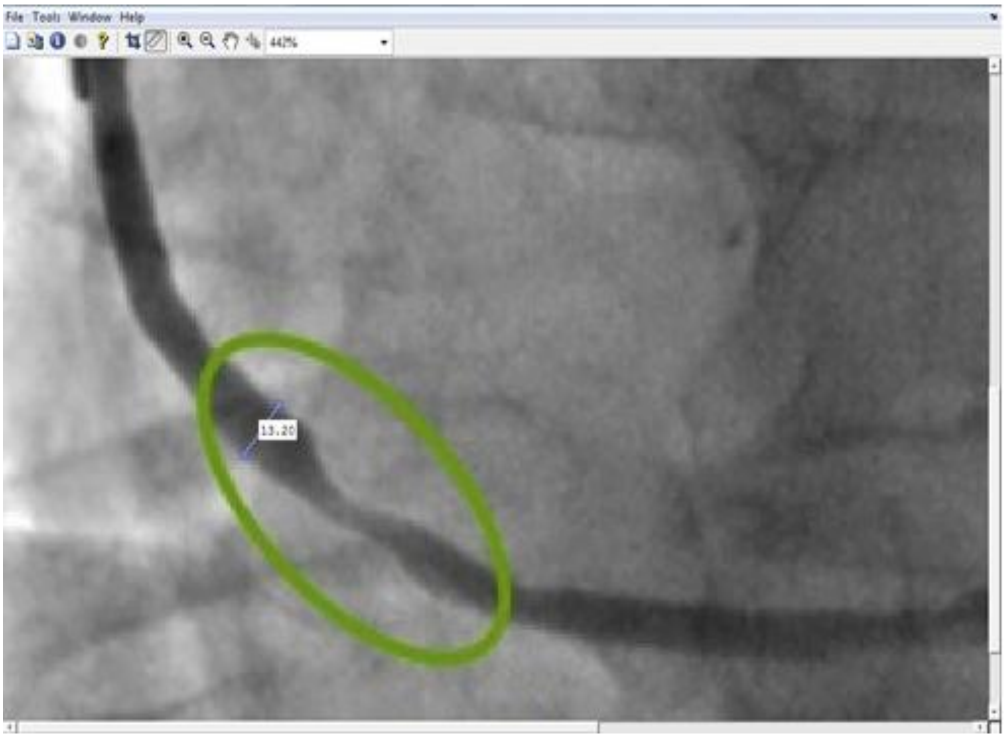


Figure 4.19: Measurement for normal diameter (D*n*).

For third step we need to get measurement for stenosis side of vessel so you can see in Figure 5.16 how is select from matlab.

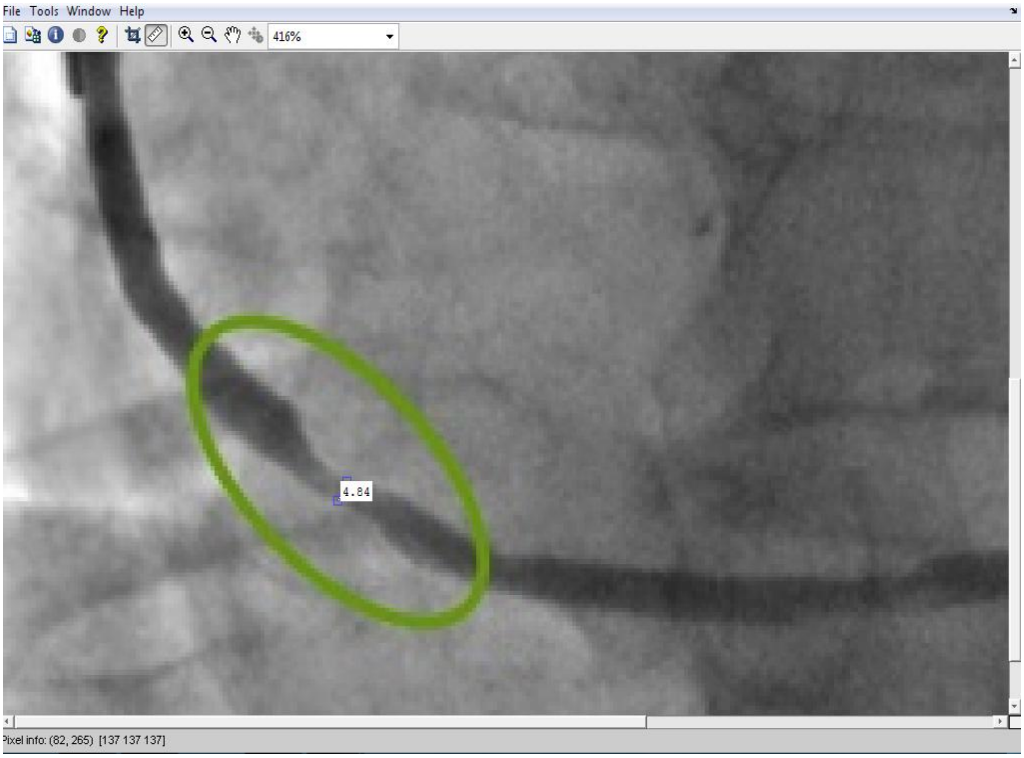


Figure 4.20: Measurement for stenosis side of vessel (D*s*).

Then we need to start calculation manually with standard formula for observing exact percentage of blockage and the formula is the same formula which we used it in our detection system.

$$\text{Stenosis } \% = \left[1 - \left(\frac{\mathrm{D}s_2}{\mathrm{D}s_1}\right)\right] \times 100 \tag{5.8}$$

Where:

D*s* is the diameter of the stenosis portion of the lesion, it is important to also need to be careful about line of interest to passed from inside of blocked area.

D*n* is normal vessel diameter where this one needs to select in the mid part of normal sized vessel.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

Coronary arteries are kind of artery which carry the blood away from the heart such as the capillaries, which enable the real exchange of chemicals and water between the tissues and the blood. Cardiac veins is the vessels that remove the deoxygenated blood from the heart muscle and these include the great cardiac vein, the middle cardiac vein, the anterior cardiac veins and the small cardiac vein [38].

The right and left coronary artery when they are healthy they are capable of auto regulation to maintain coronary blood flow at levels proper to the needs of the heart muscle. These probably narrow vessels are commonly affected by atherosclerosis (stenosis) and can become blocked therefore it causing heart attack [39].

Generally the coronary arteries are categorized as end circulation. Since they represent the only source of blood supply to the myocardium, there is very small redundant blood supply, which is why blockage of these vessels can be so critical.

In Figure 5.1 you can see the anatomy of human body which we mentioned the name of all vessel and we separated the vessel which we will discuss about them in each own respective part.

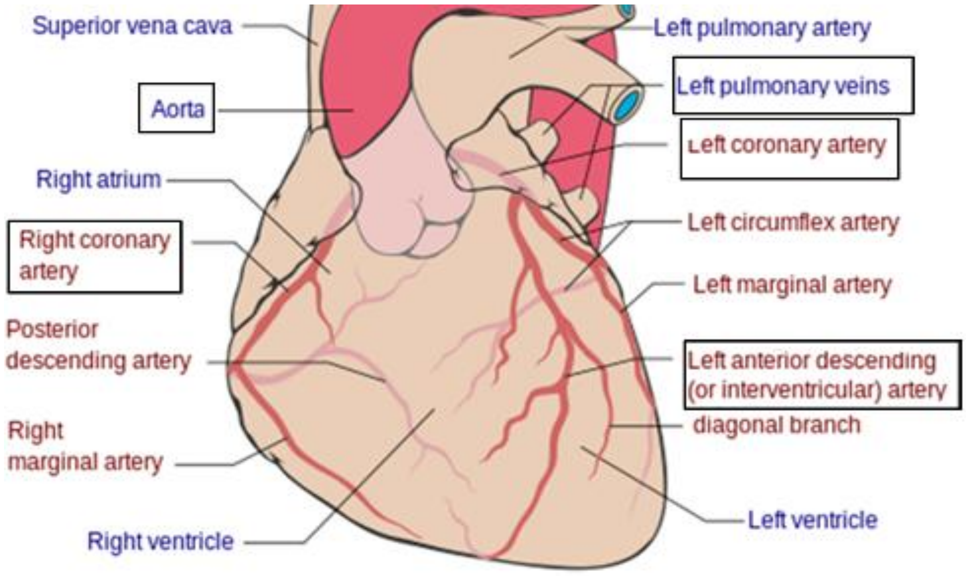


Figure 5.1: Anatomy of human heart [40].

5.2 Simulation Methodologies

- In this chapter, I use 4 main vessels for our discussion and even each of this vessel type include own database.
- For left pulmonary artery I used 6 images where all of them need for surgery in case of high and medium stenosis diseases.
- All of image size are radiology standard.

In four main part of artery discussion we included our clinical database for describing the differences of stenosis detection methods in the form of angiographic frames.

5.3 Left Pulmonary Artery

The left pulmonary artery is divided to the two one for each lobe of the lung, and this artery is shorter and almost smaller than the right passes horizontally in front of the descending aorta and left bronchus to the root of the left lung. Above side of left pulmonary artery is connected to the concavity of proxical aorta on the left and superficial part of plexus by ligamentum and in Figure 5.2 you can see the pulmonary vein by the ligament of the left vena cava [41].

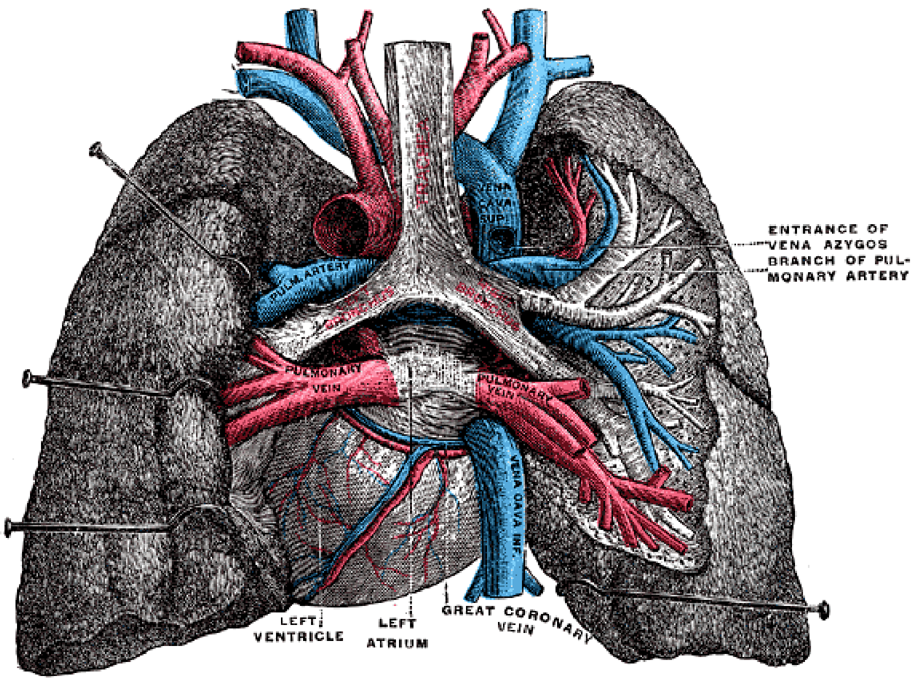
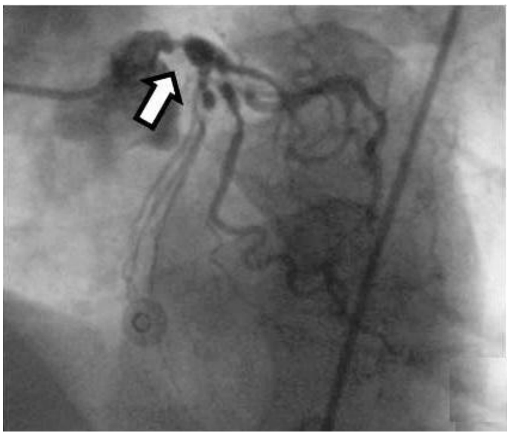
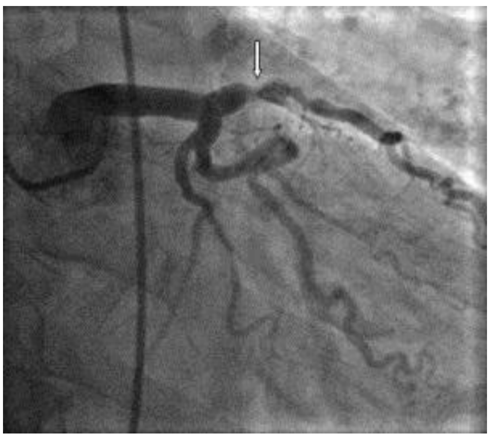


Figure 5.2: Left pulmonary artery sample [42].

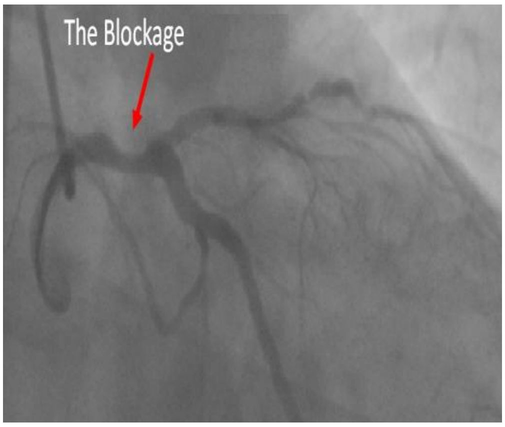


Sample 1



Sample 2

Sample 3



Sample 4

Sample 5

Figure 5.3: Clinical test image for Left pulmonary artery.

So we can start our comparison of methods according to the manual method and all of clinical images are used for these results, however first we need to understand the concept of mean square error.

5.4 Mean Square Error Analysis of Methods Introduced

The mean squared error (MSE) is one of many ways to quantify the difference between the true values of the quantity being estimated and values implied by an estimator. Clearly MSE is a risk function and it almost measures the average of the squares of the errors, and this error is the quantity by which the value implied by the estimator and it is differs from the quantity to be estimated. The quantity differences occurs because of randomness or because the estimator doesn't calculate for data that could yield an exact estimate [43].

In an analogy to standard deviation, taking the square root of MSE yields the root-mean-square error (RMSE) or root-mean-square deviation (RMSD), which has the same units as the quantity being estimated; for an unbiased estimator, the root-mean-square error is the square root of the variance, known as the standard deviation.

If Y and $\widehat{Y}$ is the vector of the true values and a vector of n predictions respectively, then the MSE of the prediction is like this formula

$$\text{MSE}= \frac{1}{\text{N}} \sum_{i=1}^{N} (\widehat{\text{Y}}_i - \text{Y}_i)^2 \qquad (6.1)$$

Where Y is vector with true value, and $\widehat{Y}$ is vector, N is start from *1* to ∞.

- It should be noted that we calculated all of errors according to the MSE.

Table 5.1: Evaluation of stenosis for pulmonary artery angiography in 5 samples.

Samples	Doctor's Opinion (Percentage)	Manual Method (Percentage)	Proposed Threshold Method (Percentage)	Proposed Segmentation method (Percentage)	Proposed K- means Method(Percentage)
Sample 1	50	52	60	49	54
Sample 2	90-95	79	68	65	83
Sample 3	85	80	89	84	81
Sample 4	50	49	61	59	50
Sample 5	60	51	50	57	57

We can see MSE results for left pulmonary artery in Figure 5.4. The MSEs are calculated by using stenosis results from 5 samples with respect to reference results in column 2. K-means generate the best performance by means of calculated MSE.

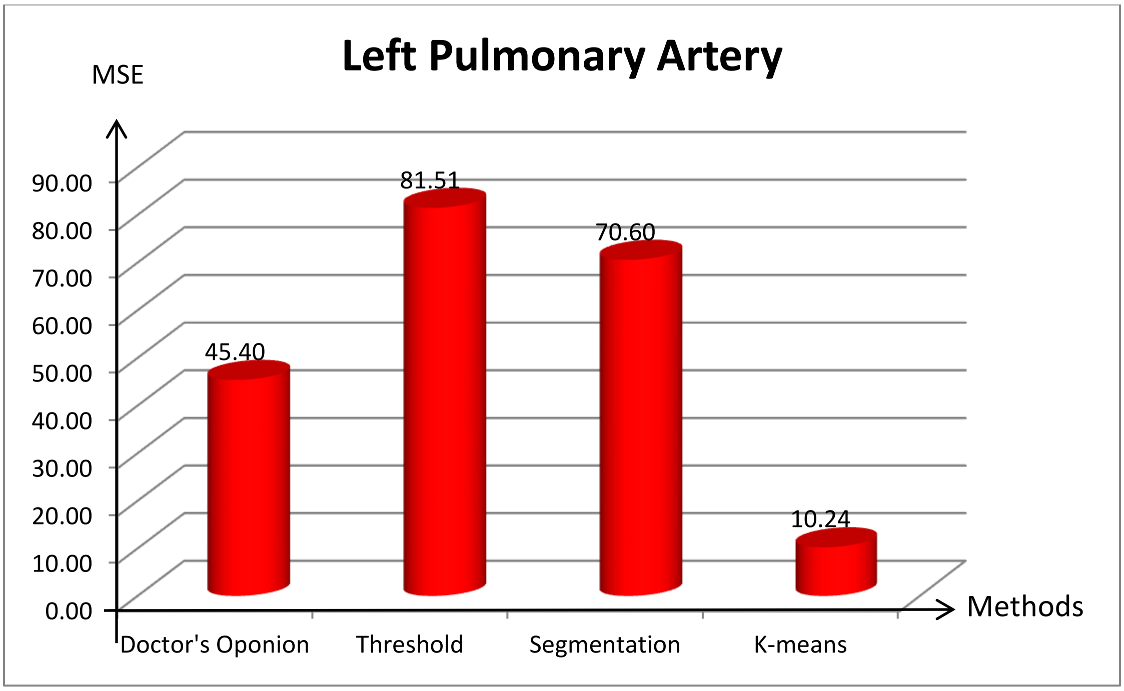


Figure 5.4: MSE for Pulmonary artery in 5 angiographic samples.

5.5 Right Coronary Artery

The right coronary artery is locating above the right cusp of the aortic valve and it circulates down the right atrioventricular furrow, toward the crux of the heart. It branches into the right marginal artery and the posterior descending artery [44].

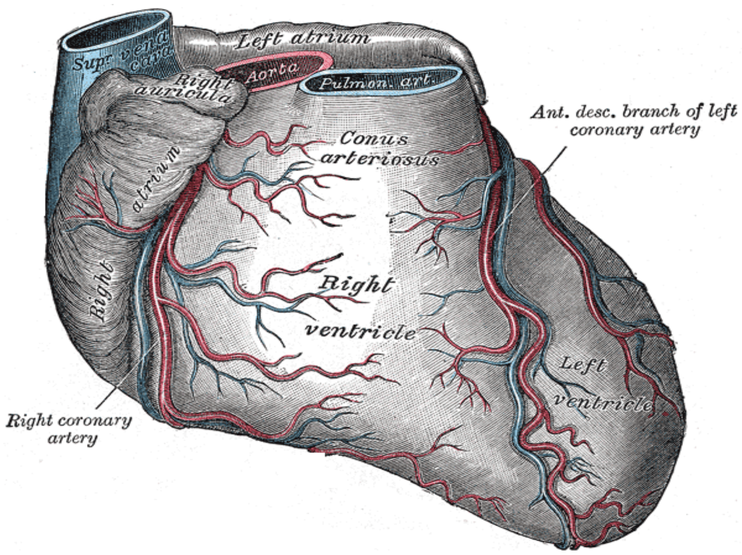
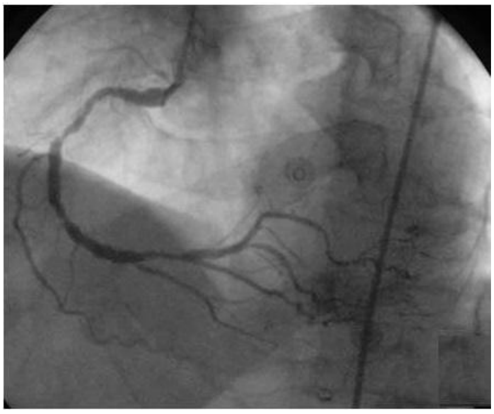
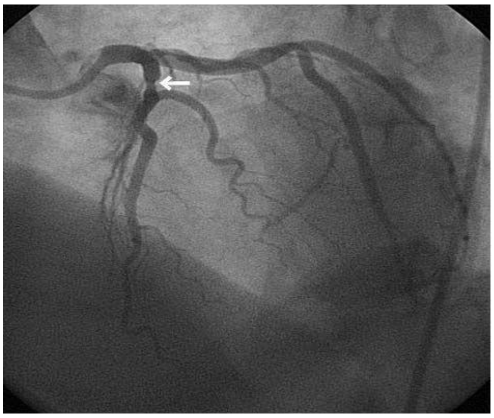


Figure 5.5: Heart Right Coronary Arteries with posterior descending [45].

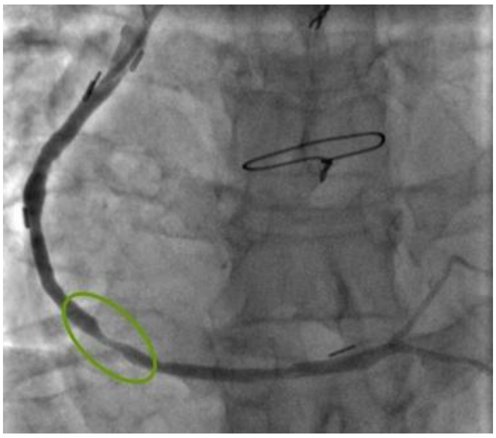
You can see our clinical test image for right coronary artery from sample 1 to 5.



Sample 1

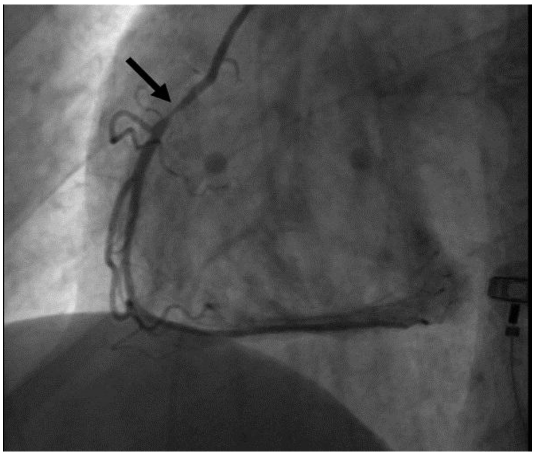


Sample 2



Sample 3

Sample 4



Sample 5

Figure 5.6: Clinical test images for Right coronary artery.

Table 5.2: Evaluation of stenosis for Right coronary artery angiography in 5 samples.

Samples	Doctor's Opinion (Percentage)	Manual Method (Percentage)	Proposed Threshold Method (Percentage)	Proposed Segmentation method (Percentage)	Proposed K-means Method (Percentage)
Sample 1	80	71	68	69	71
Sample 2	40	47	64	58	47
Sample 3	80	70	70	71	67
Sample 4	85	65	52	46	54
Sample 5	80	76	52	51	67

We can see MSE results for right coronary artery in following chart and it show that k-means methods give best results:

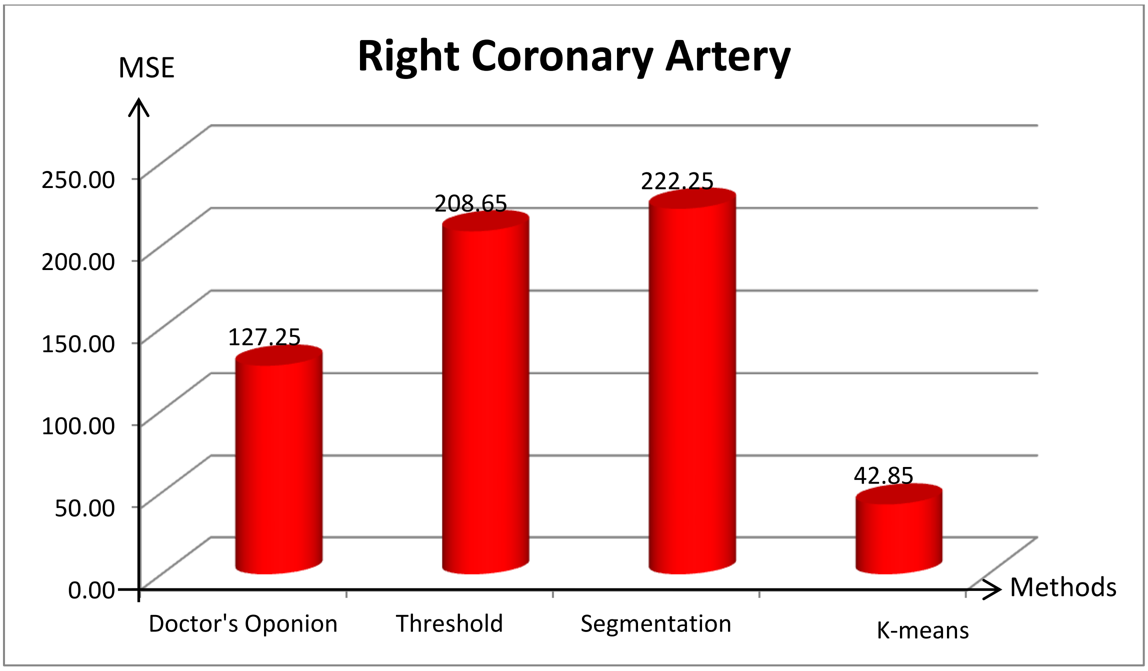


Figure 5.7: MSE for Right coronary artery in 5 angiographic samples.

We can see MSE results for right coronary artery in Figure 5.7. The MSEs are calculated by using stenosis results from 5 samples with respect to reference results in column 2. K-means generate the best performance by means of calculated MSE.

5.6 Left Anterior Descending Artery

Anterior Descending artery is locating at the left margin of the pulmonary trunk and it a branch of the left coronary artery. The left anterior descending artery is the one of commonly affected by disease, mainly atherosclerotic narrowing [46].

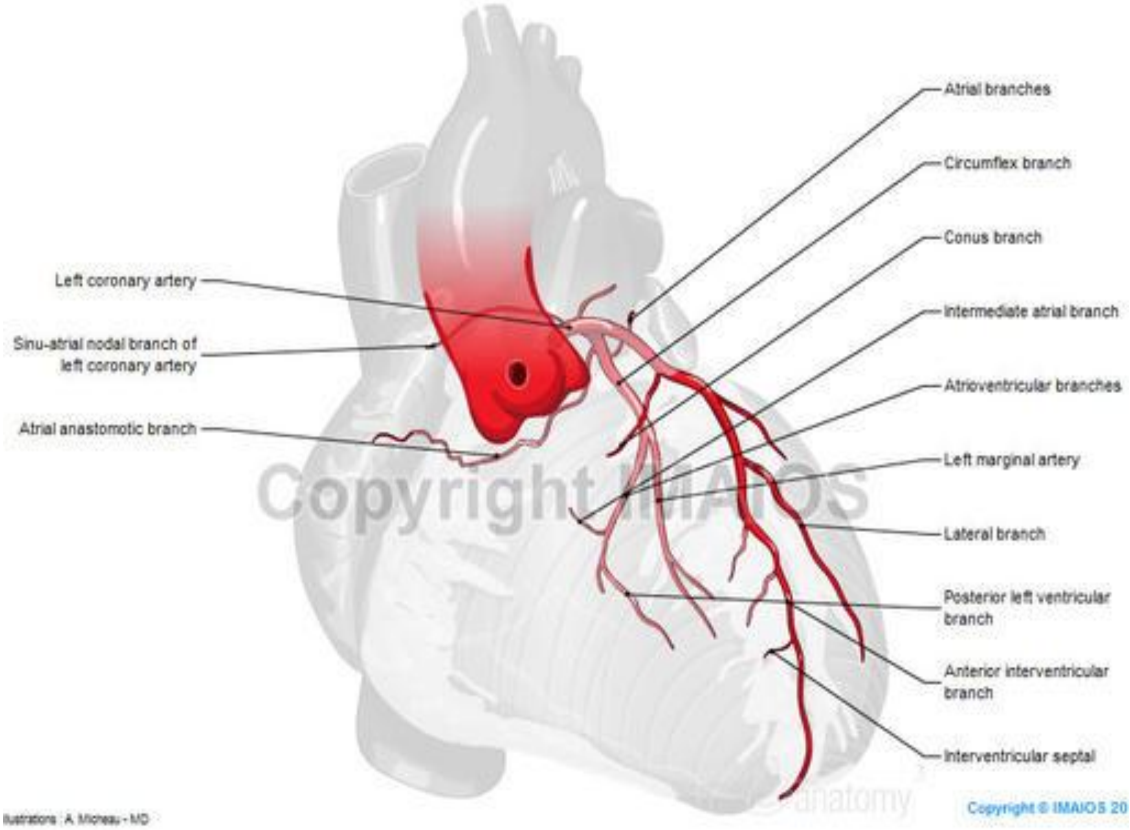


Figure 5.8: Left anterior descending artery with descriptions [47].

Our clinical test images for Left Pulmonary Artery from sample 1 to 6 in below:

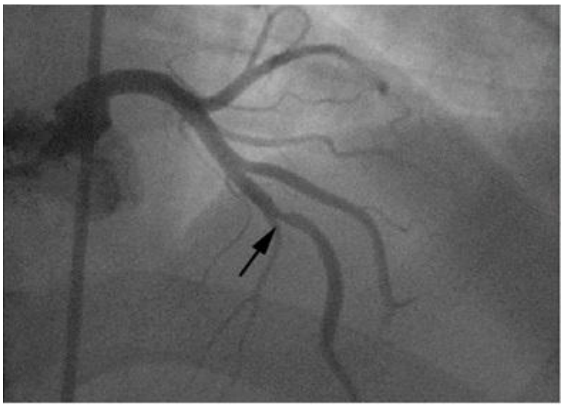


Image 1

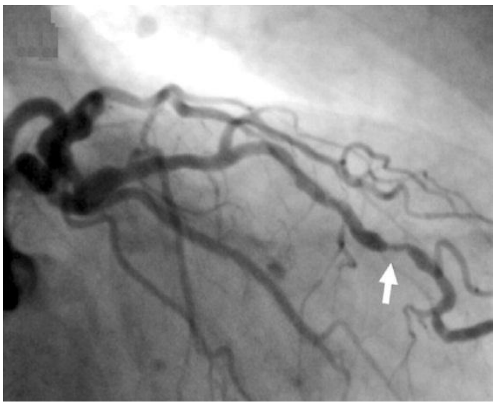


Image 2

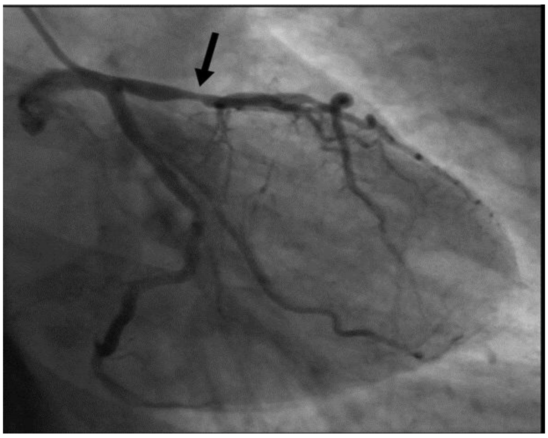


Image 3

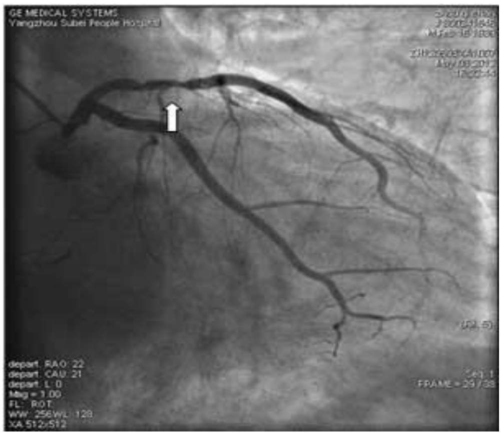


Image 4

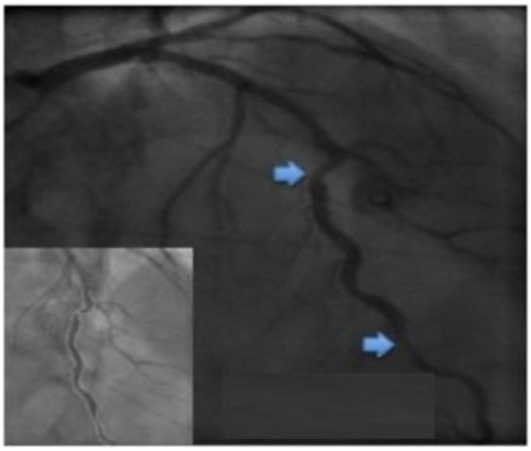


Image 5

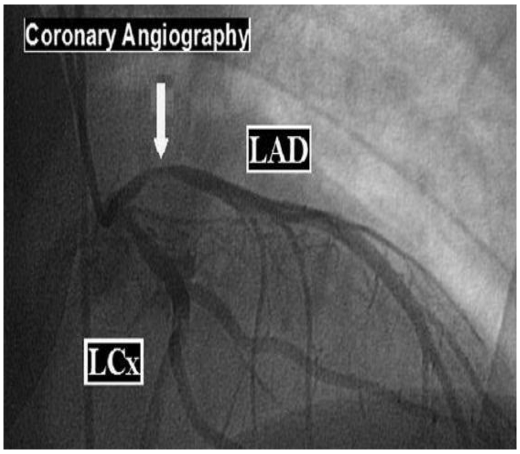


Image 6

Figure 5.9: Clinical test images for Left Anterior Descending Artery.

Table 5.3: Evaluation of stenosis for Left Anterior Descending Artery in 6 samples.

Samples	Doctor's Opinion (Percentage)	Manual Method (Percentage)	Proposed Threshold Method (Percentage)	Proposed Segmentation method (Percentage)	Proposed K- means Method (Percentage)
Sample 1	55	51	31	35	50
Sample 2	70	58	67	59	59
Sample 3	55	56	70	70	56
Sample 4	75	73	76	78	78
Sample 5	61	58	55	58	67
Sample 6	70	63	53	55	60

We can see MSE results for left anterior descending artery in following chart and it show that k-means methods gives a best results:

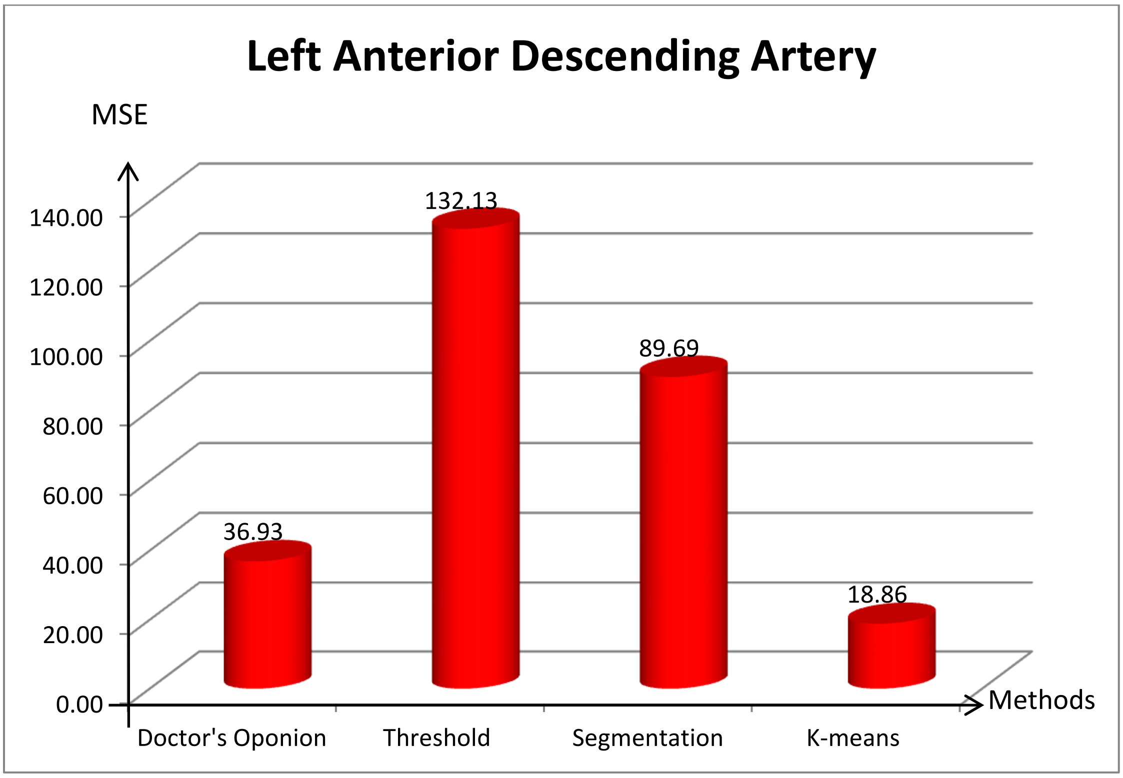


Figure 5.10: MSE for Left Anterior Descending artery in 6 angiographic samples.

We can see MSE results for Left Anterior Descending artery in Figure 5.10. The MSEs are calculated by using stenosis results from 5 samples with respect to reference results in column 2. K-means generate the best performance by means of calculated MSE.

5.7 Left Coronary Artery

Left coronary artery is one of significant artery which sometimes human body within a stress or pressure can feel pain and maybe it cause a heart attack, because left coronary artery is really sensitive in this occasion and also most of the doctors called the main artery for left coronary artery. This artery is an artery that arises from the aorta above the left cusp of the aortic valve and feeds blood to the left side of the heart [48].

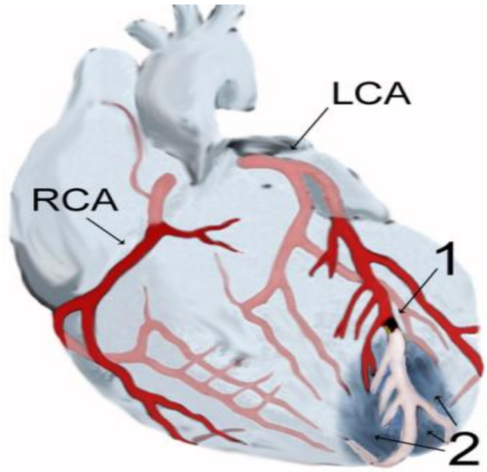


Figure 5.11: Left and right coronary artery [49].

You can see our clinical images for Left coronary Artery from sample 1 to 4

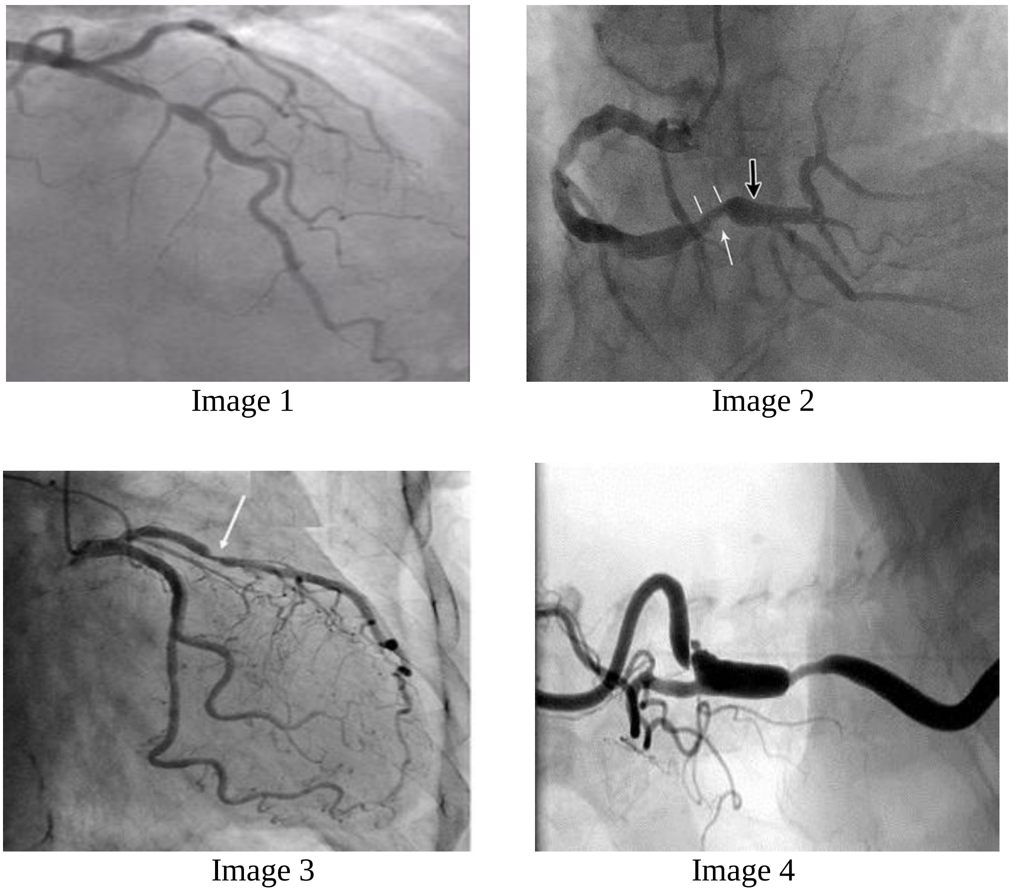


Image 1
Image 2
Image 3
Image 4
Figure 5.12: Clinical test images for Left coronary artery.

Table 5.4: Evaluation of stenosis for Left coronary artery angiography in 4samples.

Samples	Doctor's Opinion (Percentage)	Manual Method (Percentage)	Proposed Threshold Method (Percentage)	Proposed Segmentation method (Percentage)	Proposed K- means Method (Percentage)
Sample 1	90	88	74	73	82
Sample 2	95	75	73	63	82
Sample 3	85	80	88	95	90
Sample 4	85	85	83	93	90

We can see MSE results for left coronary in following chart and K-means is best:

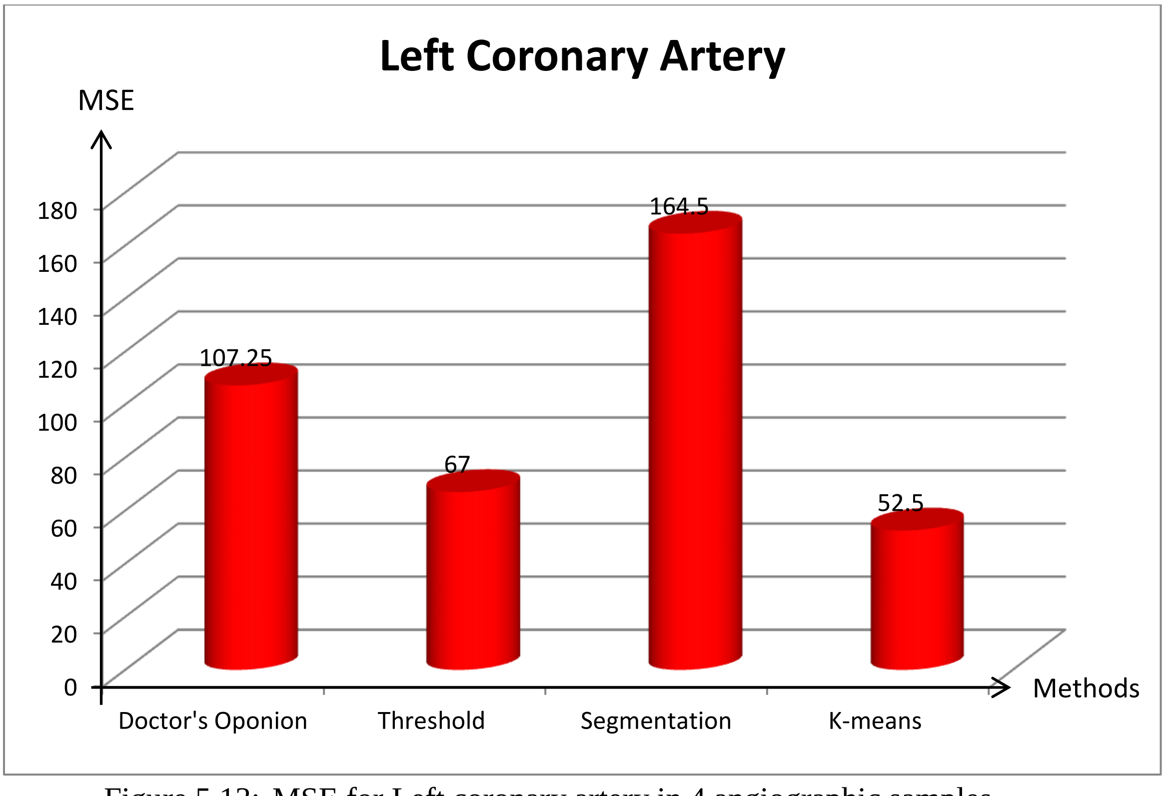


Figure 5.13: MSE for Left coronary artery in 4 angiographic samples.

We can see MSE results for Left coronary artery in Figure 5.13. The MSEs are calculated by using stenosis results from 5 samples with respect to reference results in column 2. K-means generate the best performance by means of calculated MSE.

Now in this part, we collect all results of coronary arteries stenosis in one chart and this can show us that, after using three images processing techniques for stenosis detection the K-Means method is the best method and it gives us the best result in comparing with the manual method.

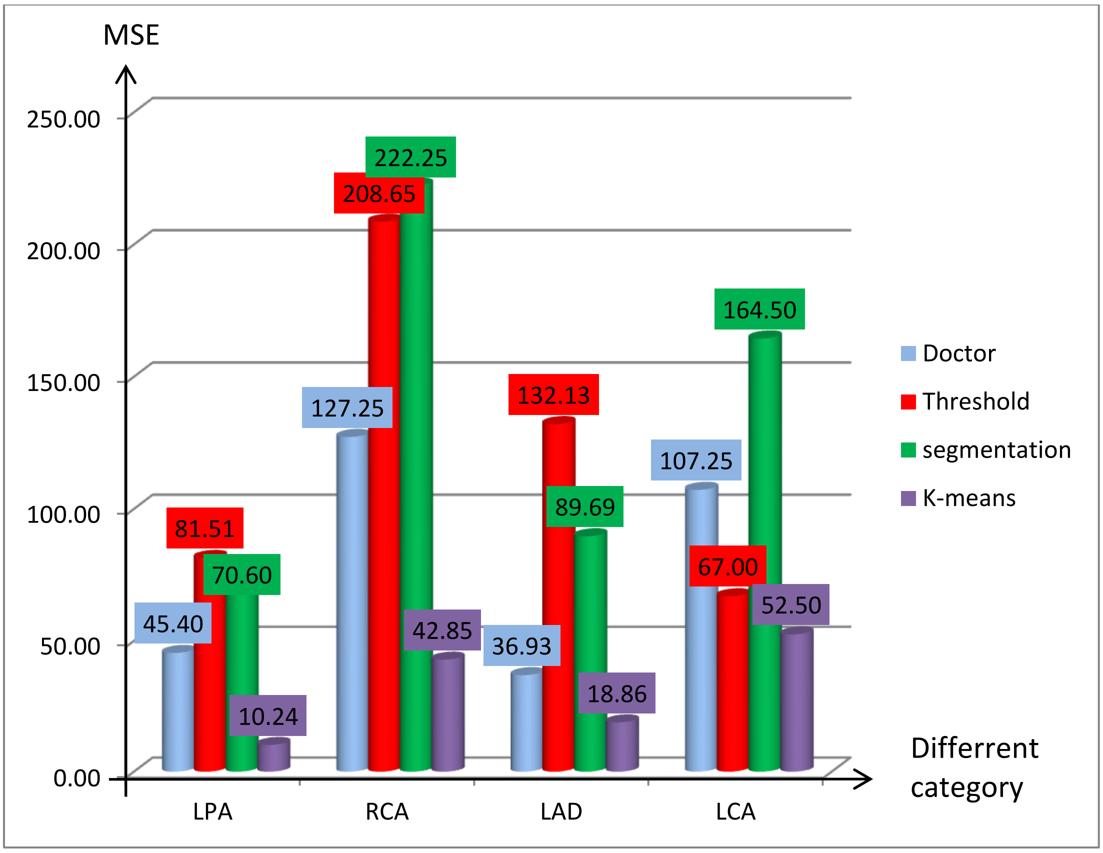


Figure 5.14: MSE for All categories of coronary diseases.

5.8 Aortic valve stenosis

The carotid arteries are the closest arteries to the aortic valve that can be felt by the doctor examining the neck and carry blood from the aorta to the brain. Patients with very significant aortic stenosis have a lower intensity of the carotid pulse and delayed up stroke which correlates with the percentage of narrowing. Aortic valve stenosis causes significant disarray to blood flowing during shrinkage of the left ventricle resulting in a loud murmur. The loudness of the murmur does not, however, correlate with the severity of stenosis. And by the way patients with mild stenosis can have loud murmurs, while patients with severe stenosis and heart failure may not pump enough blood to cause much of a murmur [50]. Now we you can see our category in table 6.5:

Table 5.5: Conventional Stenosis Classification of Doctors Evaluation.

Stenosis diseases rate	Percentage of disease (percentage)	Evaluation
Mild Coronary Stenosis	(< 50)	Medicine (Drug) treatment is enough
Moderate Coronary Stenosis	(50 – 70)	Drug treatment and / or Stent placement
Severe Coronary Stenosis	(> 75)	Stent placement / by-pass surgery

5.9 Analysis of Mild Coronary Stenosis

Mild coronary stenosis is a kind of disease that causes shortness of breath when patient go walking or in daily activities like other coronary diseases and it is large and its complications if not longer he/she go to the doctor and start medication treatment to Prevent its progression. Mild coronary stenosis is not a sufficient case of disease for surgery, because the percentage range for this kind of disease is less than 50, but it doesn’t mean that to disregard it and patient needs to refer to the doctor to start medicine treatment.

Table 5.6: MSE for Mild coronary stenosis in four methods.

Mild Stenosis diseases	Doctor's Opinion (percentage)	Manual method (percentage)	Threshold Method (percentage)	Segmentation Method (percentage)	K – means Method (percentage)
left pulmonary artery	50	49	61	59	50
Right Coronary artery	40	47	64	58	47

So according to the table we can see all errors in bar chart in below:

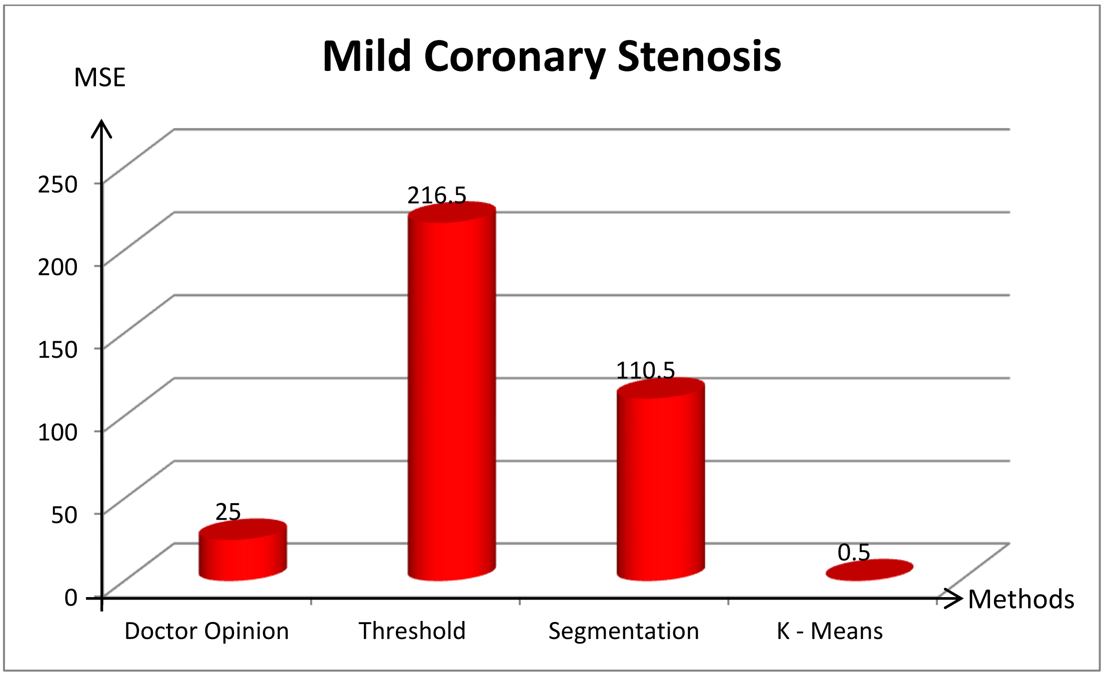


Figure 5.15: MSE for Mild coronary stenosis

5.10 Analysis of Moderate Coronary Stenosis

Moderate coronary stenosis is a kind of disease which sometimes most of the doctors give an opinion different from others and they discuss about this result many times.

Doctor’s variable evaluations can cause a confusion for some patient to trust the doctor and sometimes some doctors in such case that vessel need to stent replacement, but he/she ignore and advise to start medicine treatment.

Variable evaluation in Moderate coronary stenosis only can occur when stenosis percentage is closed to 55 or 60 percent.

Table 5.7 show Mean square error for moderate stenosis vessel:

Table 5.7: MSE for Moderate stenosis vessels in four methods.

Moderate Stenosis disease	Doctor’s Opinion (percentage)	Manual Method (percentage)	Threshold Method (percentage)	Segmentation Method (percentage)	K–means Method (percentage)
Left pulmonary artery (2 samples)	50	52	60	49	54
	60	51	50	57	57
Right Coronary artery (3 samples)	80	71	68	69	71
	80	70	70	71	67
	85	65	52	46	54
Left Anterior Descending Artery (6 samples)	55	51	31	35	50
	70	58	67	59	59
	55	56	70	70	56
	75	73	76	78	78
	61	58	55	58	67
	70	63	53	55	60
Left coronary artery (1 sample)	95	75	73	63	82

In above table we collect all data bases for moderate stenosis diseases.

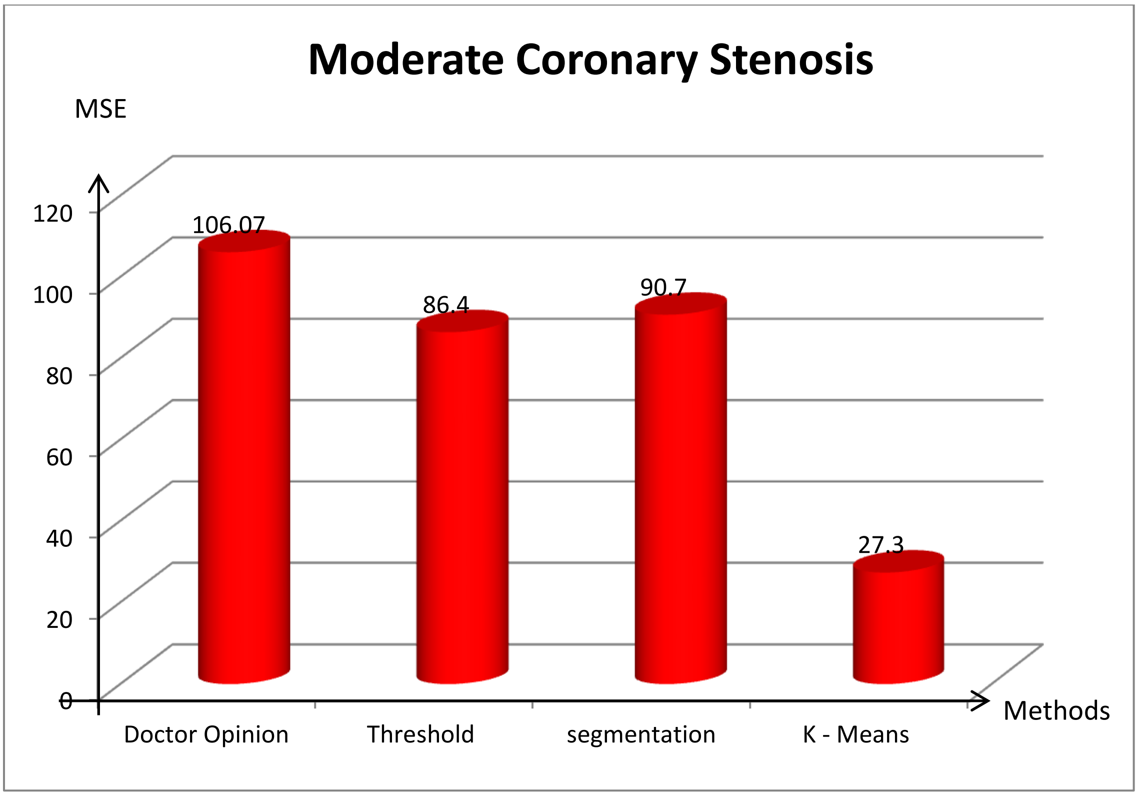


Figure 5.16: MSE for Moderate coronary stenosis

5.11 Analysis of Severe Coronary Stenosis

If stenosis percentage exceeds the 75 %, then stent placement or medicine treatment cannot help patient to improve the diseases, and the only way is by-pass surgery to help heart to blood perfusion to the other coronary vessels.

Table 5.8: MSE for Severe stenosis vessels in four methods.

Severe Stenosis diseases	Doctor's opinion (percentage)	Manual method (percentage)	Segmentation method (percentage)	Thresholding method (percentage)	K – means method (percentage)
Left pulmonary artery (2 samples)	90-95	79	68	65	83
	85	80	89	84	81
Right Coronary artery (1 sample)	80	76	52	51	67
Left Anterior descending artery (3 samples)	90	88	74	73	82
	85	80	88	95	90
	85	85	83	93	90

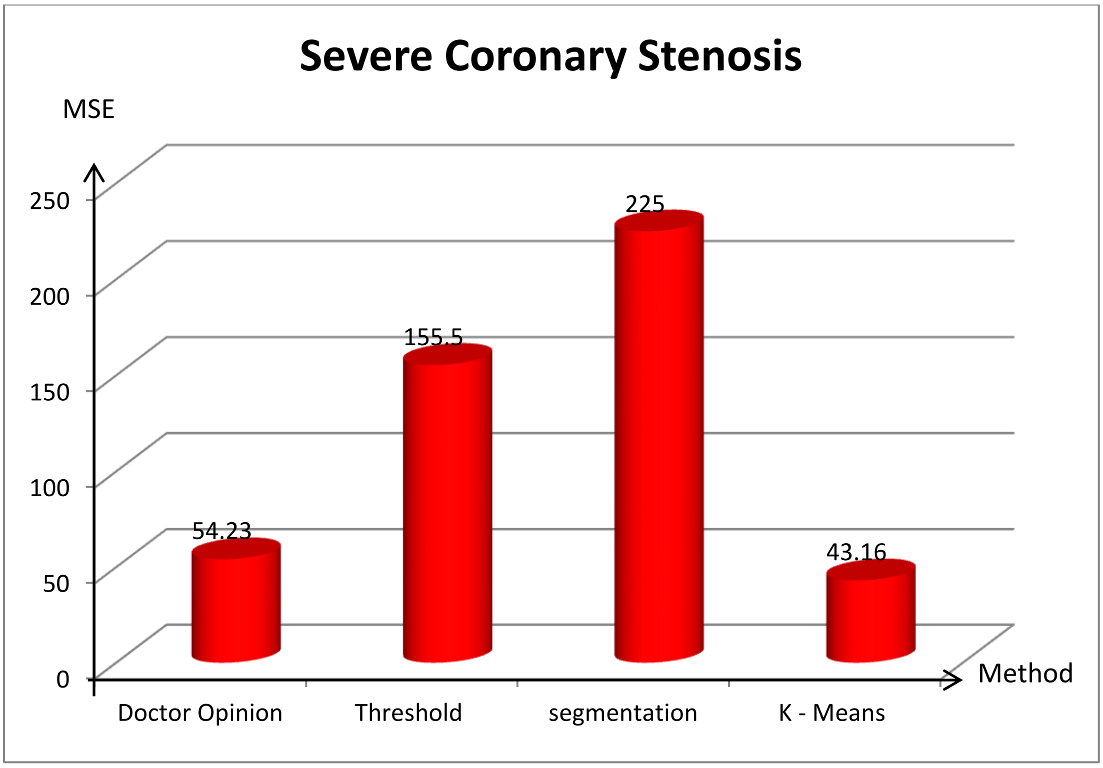


Figure 5.17: MSE for Severe coronary stenosis

5.12 Maximum Performance Error Ratio

We have developed a new metric, maximum percentage error ratio (MPER), to evaluate the quality of all methods. MPER can be defined as:

$$\text{MPER} = 10\ log_{10}(\frac{MAX^2}{MSE}) \qquad (6.2)$$

Where maximum performance is assumed to be 100 for maximum percentage and MSE is the Mean Square Error. The results of MPER are in decibel (dB). A good quality of stenosis results of a given method is expected to be more than 20 dB, below this ratio is not the acceptable range for medical discussions.

We calculated our previous results from 4 category and tables and charts can show corresponding results between methods and all of results are calculated in dB.

In table 5.9 we can see that K-Means method have better quality metric than the other methods and as mentioned before 20 dB is almost good value.

Table 5.9: MPER for all kind of coronary diseases.

Methods	Doctor's method (dB)	Thresholding method (dB)	Segmentation method (dB)	K–Means method (dB)
left pulmonary artery	23.4294	20.8879	21.5120	29.8970
Right Coronary artery	18.9534	16.8058	16.5316	23.6805
Left anterior descending	24.3262	18.7900	20.4726	27.2446
Left Coronary artery	19.6960	21.7393	17.8383	22.7984

Now we can see all methods results in following bar chart that shows that K-means have best results for any evaluation with quality more than 20 dB:

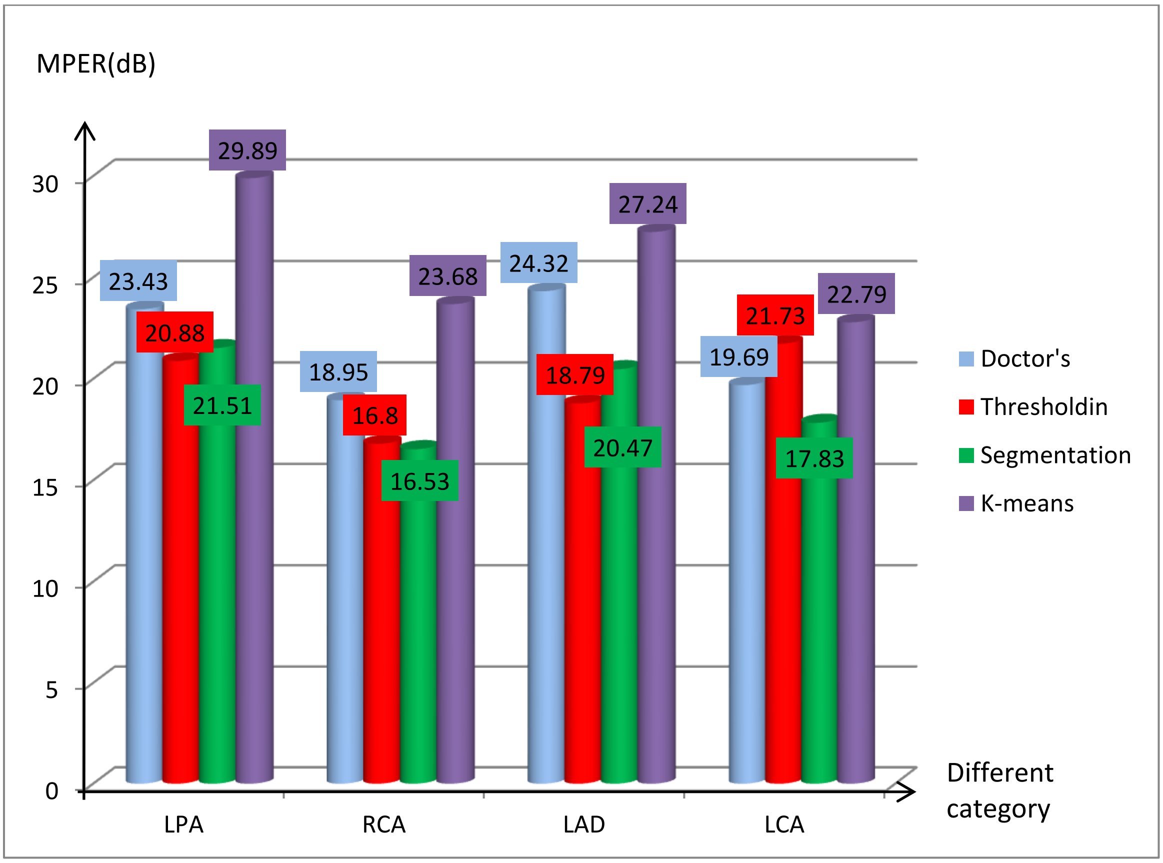


Figure 5.18: MPER calculated in all kind of coronary diseases

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this thesis a K–Means clustering based Angiographic Image Analysis to measure Coronary Stenosis method in detecting stenosis cardiac angiography images we apply three main methods, which it is include thresholding method, k-means clustering method and the segmentation method respectively.

In all part of discussion and evaluation with used the important database for understanding that the method which gives us the blockage percentage is correct or not. When we start to use the first method (thresholding), it is clearly had a far differences between standard evaluation and threshold evaluation. For the second method (k-mean clustering) we used all database and we got the comparable result which it is better than other two methods. At the end we used the segmentation method, but it is not good as k-means method, but most of the time it is better than thresholding method.

Meanwhile for the results and discussions we also assumed the other methods which we call it doctor opinion, because it is important to know doctor's evaluation and we compared with k-means; however k-means method showed better and ideal rate than others.

6.2 Future Work

The proposed method is not fully automatic because the doctor has to select region of interest manually.

In the future work, we are planning to extent our approach such that the method will automatically find ROI and process is independent of doctor supervision. Even I will work on image time intensity graph to further detail in evaluation process.

And the next things that I want to do in the future work is, for instead of apply K-means in ROI, K-means can be apply to segmented part of ROI. This would help to reduce the possible error that K-means would make in ROI.

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