Detection of Coronary Plaque and Sensing Risks Factors of Heart at early stages using various Image Processing and Segmentation Techniques

Kanika Jora† and Jyotika Pruthi‡

†Department of CSE and IT, The Northcap University, Gurgaon, India

Accepted 25 Feb 2016, Available online 05 March 2016, Vol.6, No.2 (April 2016)

Abstract

Cardiac arrest known as myocardial infarction is one of the common disease occurring in the human heart, usually causing death. Currently some of the clinical modalities are insufficient to detect at early stages. This paper shows the early detection of plaque non-invasively through CCTA images. In this paper, noise removal is being done by enhancement technique followed by global thresholding with segmentation using K-means Clustering. Further ROI extraction by stenosis using canny gradient operator with non maximum suppression with threshold values 75 to 90 and hysteresis is done. The proposed mathematical model explains the rate of change in blood flow using fluid dynamic concept by Hagen Poiseuille law and vascular wall shear stress method for quantification of healthy and diseased coronary arteries. After that we have classified the levels of heart attack as initial, mild and severe using ANFIS(Adaptive Neuro Fuzzy Inference System) tool with membership function. Computer simulation results assist in predicting the risk factors of heart attack at an early stage.

Keywords: ANFIS, Blood flow, Coronary artery, Edge gradient, Fluid dynamics, Heart attack, Stenosis.

1. Introduction

Heart disease commonly caused due to atherosclerosis, an accumulation of fatty substances on the inner lining of coronary arteries causing blockage of blood flow.

When the flow of blood is totally blocked, the result is heart attack. According to the research, this disease was declined somewhat since 1990, lot of deaths caused and affected adversely. 17 million people are affected according to World Health Organization. Recently in London, Dr Anoop Shah introduced a new blood test technique to detect the heart attack. Heart attacks are occurred when coronary arteries are partially blocked or clogged. Blockage is caused due to the regular fixation of athero-plaque which is a waxy material. Due to this, arteries become narrower and harden itself which means there is a lack of oxygen known as myocardial ischemia and reduction of blood flow leads to the damage of heart. It causes in every men and women in any age groups.

The main objective of this research is to detect the atherosclerosis plaque and risks of heart in non invasive manner at early stages for further diagnosis. Now days, image processing plays a vital role in reducing the overheads of clinicians, they can understand the diagnosis of patients in better manner. This paper proposes various image processing modalities to extract relevant information through CCTA images for the prediction of disease. Starting from preprocessing, median filters are applied to remove the noise and get the enhanced image. The most important step is segmentation which is done through global thresholding technique followed by K-means clustering to extract the crucial information for the coronary arterial branches. Stenosis, post processing context which considers the region of Interest or blockage is detected by canny edge gradient operator by applying gradient magnitude function with non maximum suppression and hysteresis. Proposed mathematical model is used for analyzing the change in blood flow rate through cardiac blood vessels. This mathematical model has been designed using fluid dynamics concepts including Hagen Poiseuille law (S.Agarwal et al,2013) and...
vascular wall shear stress method. Degree of stenosis (blockage) has been measured by calculating the cross sectional area of blocked and unblocked coronary arteries using ellipse curve fitting method. After that classification has been done using ANFIS tool for characterization of severity of heart attack as initial, mild and severe.

2. Research Workflow

The following research workflow shows the steps to predict the risk factors of heart attack at early stages:

2.1 Acquisition of Data

Experimentation have been done on computed tomography angiogram(CTA) images which is gathered from Dr.Balabhai Navanati Hospital, Mumbai and Cardiac Life Center, Ludhiana. The image is of normal age group male and female of approx 40 to 65 years.

2.2 Preprocessing of Image

2.2.1 Enhancement of Image

Image Enhancement is the visual perception of an image to improve the quality. In this various median filters are applied on gray level formation CTA image for the removal of noise and better visualization as given in (S.Aggarwal et al,2013) shown in figure1.

![Fig.1](image1.png)

(a) a real ccta image of 40 years old healthy man.  
(b) gray label image  
(c) median filter image

2.2.2 Segmentation of Coronary Arteries

Segmentation is the crucial component in image processing. It is to extract the coronary artery structure from computed image by applying global thresholding modality through K-means clustering to segment color in automated fashion using L*a*b color space as shown in figure2.

There are also some other segmentation techniques like watershed and texture segmentation applied to show different behavior of this CTA image as shown in figure3.

![Fig.2](image2.png)

Plaque detected through K-means clustering

![Fig.3](image3.png)

(a) cluster1 image  
(b) gray label image  
(c) texture image

Clustering is a way of grouping of objects. K-clustering treats each object as having a location in space known as L*a*b color space, it visually distinguish one color from another. It finds partitions such that objects within each cluster are as close to each other as possible and as far as from other objects of cluster as possible.

K- clustering requires that you specify the number of clusters to be partitioned and a distance metric to quantify how close two objects are to each other. K-means clustering algorithm defines K-center for each cluster. These centers should be placed in cunning way as there are many different results in different location. Next step is to take each point belonging to a given dataset associated to nearest center. If no point is left, first step completed and now recalculate the centers, then a new binding has to be done between same dataset points and nearest data centers. Finally it aims at calculating euclidean distance between the centers.

\[
J(V) = \sum_{i=1}^{c} \sum_{j=1}^{c} (||x_{i} - v_{j}||^{2})
\]  

(1)
Ci= number of data points in ith cluster
Cj= number of data centers

2.3 Stenosis of Coronary Branches

Stenosis is the condition where the arteries contracts or in other words narrowing of arteries, which in severe cases creates complete blockage. We have considered stenosis or blockage as ROI detection and applied canny gradient edge operator with threshold value from 70 to 90 on segmented image for preserving high spatial frequency regions corresponding to edges as shown in figure 4 and figure 5.

2.4 Mathematical Modeling of blood flow

Blood is an incompressible non-Newtonian fluid but such liquid motions are complicated. As in Newtonian fluid viscosity only changes with the change in pressure or temperature, it has constant viscosity which is exactly opposite in non Newtonian fluid as explained in (S.Agarwal et al, 2013). The contraction and relaxation of ventricles and atria visualizes blood flow in coronary arteries in (C.Corciova et al, 2012) The viscoelastic model of Skalak and Schimid-Schonbien (Fibich et al, 1993) is followed by the following research in which pressure changes in linear form related to strain, such that

\[ \Delta P = aE \]  \hspace{1cm} (3)

Where \( \Delta P = P_A - P_V \); pressure differences of atria and ventricles. Now blood flow which is incompressible, non homogeneous and non Newtonian fluid depends on vessel diameter and resistance in cardiac-vascular system as described in Hagen Poiseuilli’s law.

\[ Q = -\frac{n \alpha^4}{3 \mu} \Delta P \]  \hspace{1cm} (4)

Where Q represents blood flow, l represents length of artery, a represents diameter of artery and \( \mu \) represents blood viscosity.

The relation between vessel diameter and resistance is inversely proportional as explained in below Eq.

\[ R = \frac{P_A - P_V}{Q} = \frac{8 \mu l}{\pi a^4} \]  \hspace{1cm} (5)

where \( R \) represents fluid resistance.

Blood flow is also dependent on coronary artery’s wall that produces stress explained in (C.Corciova et al, 2012) given below

Vascular wall shear stress = \( \mu \frac{\delta v}{\delta r} \) \hspace{1cm} (6)

Poiseuille’s law is used to determine shear stress rate as

\[ \gamma = \frac{8 \mu}{a} \text{ or } \gamma = \frac{32 \mu}{\pi a^3} \]  \hspace{1cm} (7)

2.5 Degree of Stenosis

2.5.1 Cross Sectional Area of Arteries using Curve Fitting Method

The difference between healthy and diseased arteries is explained by area of segmented coronary arteries by using ellipse curve fitting method from (Milos et al, 2007) as a second order central moment.

\[ \frac{1}{1+\Sigma_{i=1}^{i+j+k} (p_i-p_i')}^2 \]  \hspace{1cm} (8)

Where \( \mu \) is the central moment of the shape and corresponding ellipse fit. Now area of curve fitting is calculated using Eq.9 given below as shown in table 4.

\[ A_0 = \pi \cdot r1 \cdot r2 \]  \hspace{1cm} (9)

Where r1 is semi major axis and r2 is semi minor axis.
2.5.2 Error Rate to Detect % Stenosis

The symbol of blockage or stenosis can be shown by the variations in the area of artery. How much blockage inside the cardiac artery is quantified by Eq.10 to measure risk factors of heart attack as shown in Table 4.

\[
% \text{Stenosis} = \frac{A_N - A_B}{A_N} \times 100
\]  

(10)

Where AN is the normal artery area (without blockage) and AB is abnormal artery area (with blockage).

3. Result and Computations

The evaluation has been done based on the mathematical model for cardiac blood flow system which includes both diseased and healthy factors. Computerized simulation has been done on MATLAB (R2010).

3.1 Clinical Parameters

This research includes diseased as well as healthy Left Coronary artery (LCA) and Right Coronary artery (RCA) CCTA images of both women and men. Simulated results are based on following clinical parameters such as length, diameter of coronary arteries, velocity and blood viscosity blood flow rate.

Table 1 Simulation of blood flow rate based on clinically approved parameters

<table>
<thead>
<tr>
<th>Coronary artery</th>
<th>Sex</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Blood viscosity (10^-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCA</td>
<td>M</td>
<td>4.6±.6</td>
<td>9.6±4.4</td>
<td>3.67±0.44</td>
</tr>
<tr>
<td>RCA</td>
<td>M</td>
<td>3.5±.7</td>
<td>123 to 141</td>
<td>3.67±0.44</td>
</tr>
<tr>
<td>LCA</td>
<td>F</td>
<td>4.1±.8</td>
<td>8.5±4.2</td>
<td>3.30±0.20</td>
</tr>
<tr>
<td>RCA</td>
<td>F</td>
<td>3.2±.9</td>
<td>120 to 134</td>
<td>3.30±0.20</td>
</tr>
</tbody>
</table>

RCA= Right coronary artery, LCA= Left coronary artery, F= Female, M= Male.

3.2 Blood Flow Rate in Healthy or Diseased Artery

Table 2 Normal and patient specific clinical parameters

<table>
<thead>
<tr>
<th>Coronary artery</th>
<th>Sex</th>
<th>Length (mm)</th>
<th>Healthy coronary</th>
<th>Diseased coronary</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCA</td>
<td>M</td>
<td>9.4</td>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>RCA</td>
<td>M</td>
<td>127</td>
<td>4.5</td>
<td>3.8</td>
</tr>
<tr>
<td>LCA</td>
<td>F</td>
<td>8</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td>RCA</td>
<td>F</td>
<td>125</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

On the basis of Table 2, we have measured fluid resistance and blood flow rate of corresponding coronary arteries from Eq.(4) and Eq.(5) respectively.

3.4.2 Measurement of Blood Flow Rate

3.4.3 Measurement of Wall Shear Stress Rate

3.4.4 Classification

Risk factors of heart attack can be classified on the basis of 3 levels as shown in Table 5.

<table>
<thead>
<tr>
<th>Levels</th>
<th>% Blockage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0 to 20%</td>
</tr>
<tr>
<td>Mild</td>
<td>20 to 50%</td>
</tr>
<tr>
<td>Severe</td>
<td>Above 50%</td>
</tr>
</tbody>
</table>

Table 5 Levels of heart attack
In this research work, we use a classifier named as ANFIS (Adaptive Neuro Fuzzy Inference System) to classify levels of heart attack on the basis of healthy and diseased cases. ANFIS based classifier works as a diagnostic tool to help doctors in the classification of heart attack disease. The ANFIS is a inference model put in the framework of adaptive systems to facilitate learning and adaptation from (I.Guler et al,2005) Classification has been done on 5 training dataset and 5 testing dataset images as shown in Table 6 and results for ANFIS tool with membership function results are shown in Figure 10.

**Table 6** Dataset for training and testing images

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of training images</th>
<th>No. of testing images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy artery</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Diseased artery</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 7** Levels of risk factors of heart attack in terms of blockage

<table>
<thead>
<tr>
<th>Coronary artery</th>
<th>Sex</th>
<th>Area without blockage (mm2)</th>
<th>Area with blockage (mm2)</th>
<th>%Blockage (stenosis)</th>
<th>Level of blockage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCA</td>
<td>M</td>
<td>0.011</td>
<td>0.007</td>
<td>36.36%</td>
<td>Mild</td>
</tr>
<tr>
<td>RCA</td>
<td>M</td>
<td>0.010</td>
<td>0.005</td>
<td>50%</td>
<td>Severe</td>
</tr>
<tr>
<td>LCA</td>
<td>F</td>
<td>0.009</td>
<td>0.004</td>
<td>55.55%</td>
<td>Severe</td>
</tr>
<tr>
<td>RCA</td>
<td>F</td>
<td>0.005</td>
<td>0.004</td>
<td>20%</td>
<td>Initial</td>
</tr>
</tbody>
</table>

**Conclusion**

This research proposed a semi automated approach for enhancement and segmentation of coronary branches as well as quantification of degree of stenosis. The modeling of blood flow gives the worthy conclusions with an observation that variations in cardiac vessel diameter make wide changes in blood flow rate. ANFIS classifier differentiated between healthy and diseased cases for early prediction of risk factors of heart attack. According to the further needs there should be enhancement in the area of better findings.

**Acknowledgement**

I would like to express my sincere gratitude to my project guide Ms. Jyotika Pruthi, Assistant Professor, ITM University, Gurgaon, Team of Dr. Balabhai Navanati Hospital, Mumbai and Dr. Manpreet Singh Bindra, Cardiologist, Cardio life care Ludhiana for their guidance and help which helped out to carry this research work.

**References**