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Plaque Layer Identification in IVUS Images by Iterative based Energy Minimization of Contour Method (IEMCM)

S. Sridevi, **M. Sundaresan**

Abstract: ***Atherosclerotic plaque is the major cause of coronary heart artery diseases. Heart artery plaque layer analysis is one of the most important and challenging problem, which can be determined by using Intravascular Ultrasound (IVUS) Cross Sectional images, which is an excellent ultrasound study system for extracting and to easily identify the plaque layer by using the shape parameter measurements. This paper presents and elucidates the novel approach to find out the plaque layer with the help of the artery cross sectional layers determination, which are adventitia, media, intima and lumen layers. This system measures the layer's performance to make the clear way to identify the plaque layer, which proposes a new method namely Iterative based Energy Minimization of Contour method (IEMCM). The cross sectional IVUS acts as an input image for processing and analysis of the plaque layer based on the IVUS Simulation study Measurements of coronary vessel wall dimensions and shape measurements. The proposed method produced high accuracy when compared to the existing methods.***

Key Words: Atherosclerotic plaque, Coronary Heart Artery, Energy Minimization, Intravascular Ultrasound, Left Anterior Descending, Right Coronary Artery.

I. INTRODCUTION

Ultrasound imaging technology is one of the non-invasive procedures and it is safe, fast assessment and also it is cost effective to produce the IVUS images. There are wide Varieties of Ultrasound images and they are Intravascular Ultrasound image, echocardiogram, 3Dimensional, 4Dimensional and Bone Sonography [1]. This paper reviews and provides the detailed function about the intravascular ultrasound object layers. The Intravascular ultrasound is a diagnostic image testing technology. It is one of the best technologies in the world and it can be easily used to find out the coronary artery disease [2].

It demonstrates the anatomy of the chest artery wall for the living animals and human [3]. It has led to an explosion of better understanding and research on both the behavior of the coronary artery disease process and the effects of different treatment strategies for changing the evolution of the coronary artery disease process. IVUS produces some of the high frequency sound waves, which are used to provide the picture of heart, the image that represents the inner side of the heart from the chest wall of artery and the ultrasound echoes are converted into pictures on a monitor to produce a picture of heart coronary arteries and other vessels wall in patient's body [4].

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II. REVIEW OF LITERATURE

R.Ravindraiah et.al [5], presented that the Intravascular US (IVUS) is a medical imaging technique that allows clearly predicting and assessing the coronary arterial wall of echo morphology. IVUS is considered as a suitable medical imaging technique for characterization of the coronary plaque layer composition. This paper involves and intends to model the atherosclerotic plaque layer through the analysis of the envelope backscattered IVUS images. The Gaussian Mixture Model using Expectation- Maximization algorithm performs the smoothing of the image, at that time some desired data is neglected.

Hassen Lazrag [6] describes the segmentation method based on active contours method and fuzzy clustering method proposed for automatic lumen layer contour detection in IVUS. First, the contour initialization was performed automatically using Fuzzy c-means through spatial image information for process. The modified FCM algorithm can efficiently extract the boundary of interest in IVUS image. This has been done only for manual intervention of lumen detection. However, the above system concentrates only on the extraction of the lumen layer contour.

K.V. Archana and Dr.R.Vanithamani [7] reviewed recently developed image processing methods for the detection of luminal and media borders. Ivus image layer borders are detected based on the Edge tracking and active contour method. The above study results are says about the weakness of quality metrics and also lack of the detection of lumen border.

Vaishali Naik and R.S.Gamad [8] explained the standard level set Segmentation technique. The above said techniques evaluate only the statistical parameter of an image. But do not concentrate on the other then strengthen parameter like sensitivity specificity and accuracy.

The above limitation can be overcome by using the following proposed method.

III. IVUS WORKING MECHANISM

IVUS is one of the catheter technology based on diagnostic imaging testing procedure used to view the inner vessel wall of the coronary artery and their layers. It can provide several other medical exams for the test of the diseased artery [9]. The Ultrasound Sound waves are used in IVUS imaging systems that are produced by a transducer.

The IVUS produces the high frequency sound waves that travel through a muscle organs structure inside the body and the echoes are converted into picture, and produces detail information about the coronary interior vessel wall of the artery [10].

IV. IVUS IMAGE LAYER ANALYSIS

The coronary heart artery shows the distinct circular layers as shown in Figure 1, which are outside limit of the artery which is called as adventitia layer [11]. Actual vessel wall of the artery is called media. The intima is the third layer of endolithium or other cells that makes the direct contact with the vessels inside the artery and Lumen area is the real open channel of the coronary heart artery [12].

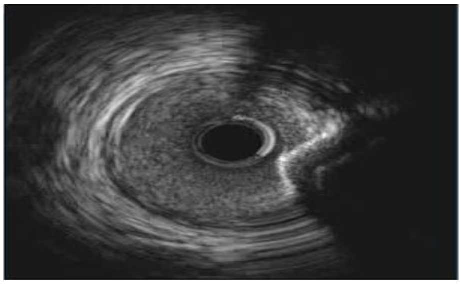


Figure 1: Coronary artery IVUS Image

The normal arteries are in narrow form. But diseased arteries are stiffened by plaques. The lumen layer is the real open channel of the artery through which the blood flows.

V. PROPOSED METHOD

A. Iterative based Energy Minimization of Contour Method (IEMCM)

The IEMCM method is defined by set of n point's z_i where i= 0, n-1. There are two separate energy terms, they are internal and external (Image) energy, which are used to control the deformation and fitting of the contour onto the image (eq 1).

$$E_{contour} = \int_0^1 E_{internal}\,(z(s)) + E_{image}\,(z(s)) + E_{con}\,(z(s))ds \qquad \text{Eq. 1}$$

The image or external energy contains the features like Line, Edges and terminations that are present in an image I(x, y) (eq 2).

$$E_{image} = E_{line}w_{line} + E_{Edge}w_{Edge} + E_{term}w_{term} \qquad \text{Eq.2}$$

Where w_{line}, w_{Edge} and w_{term} are weights of the salient features of the image and higher weights indicate that the features will have a large contribution over the image. Here the line function is the representation of the intensity in an image. The edge function is based on the directional change in the intensity of an image and then termination function is used to represent the curvature of the slightly smoothed image which is used to detect the corner and terminations in an image.

Based on the above observation the proposed IEMCM method is defined as follows (Figure 2(a) and 2(b)):

$$Image_{energy} = I(x,y) + -|I(x,y)|^2 + G_\sigma * I(x,y) \qquad \text{Eq..3}$$

getAvgdistance() → Compute the average distance among the contour used for the normalization of the continuity energy.
computeCG → Compute the centre of the Gravity.
initializeEnergy(old=0, new =0) →initial values of the energy
Approximatedcontour()→create the approximated contour
MyContour.current()→set the initial position
Get the coordinates and energy of the coefficients
Compute the energy term like internal and image energy
Compute and store all the energies for normalization
Compute the neighborhood position and the limits.

Figure 2(a): Algorithm of IEMCM

Iterative procedure of IEMCM

```
//Iterative Procedure initiated//
If(MyContour.current = start ){
Prev=(contournode *) end;
Next=(contournode *) MyContour .current → next;
If ( ++countIter > 1)
Break; } else {
If (MyContour.current == end){
Prev = (Contournode * ) MyContour.current →
prev;
Next = (Contournode * ) start; } else {
Prev = (Contournode * ) MyContour.current →
prev;
Next = (Contournode * ) MyContour.current →
next;
```

Figure 2 (b): Computation of IEMCM

The proposed method is having the following phases as shown in Figure 3. The first phase can be used to extract the dimensionality reduction for specific structure in image. When the input data is too large for processing, then this system involves and transforms the data into a reduced representation for processing.

The first phase contour initialization, involves easy making of the curve, understanding the object outline for plaque layer analysis. The Second phase can be used to determine the coronary artery layers as adventitia, media and luminal layers. The coronary artery Plaque layer formation can take place within the media and it reduces the dimensionality in the area of lumen cross sectional area.

Third phase can be computing the shape parameter measurements in each and every layer as luminal adventitia, luminal, media and plaque layer. Iterative based Energy Minimization (EM) of Contour forces can generate curves that can move to the target within images to find object boundaries. The EM forces could be used to extract the image features for processing.

It is one of the flexible cure or surface method to separate the different tissue regions and to refine the image regions and to extract contours from IVUS Images with the help of Energy Minimization (EM), which involves two different phases as Contour initialization and contour refinement.

The last phase, contour refinement process, is the final stage which can iteratively select the image features and also accurately extracts the image information from the cross sectional IVUS coronary arteries. Coronary heart artery IVUS image extraction considers the different types of irregularities as IVUS image region and boundaries that contains with sharp holes, edge points, concavities, contours and curves.

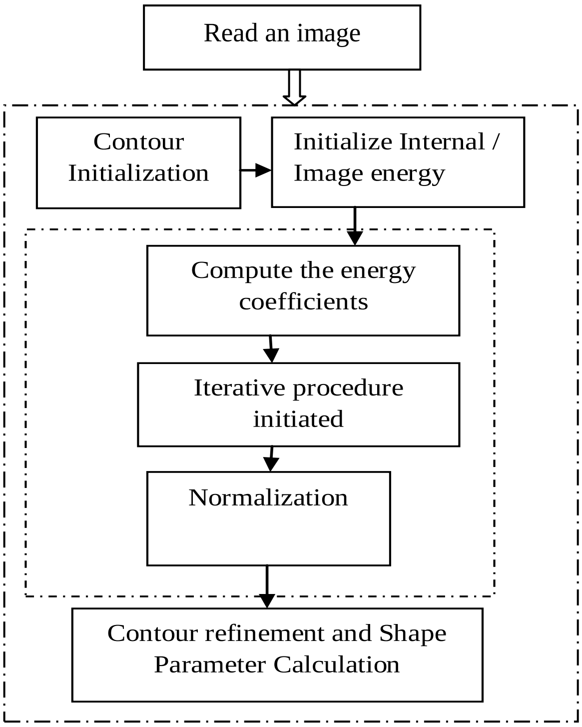


Figure 3: Framework of the proposed Method

VI. SURVEY OF RISK FACTOR ASSESSMENT

Risk is one of the most important factors for analyzing the plaque layer. This system assesses the various types of factors such as beginner, intermediate, and advanced stages, which can be recommended for age group of men between 40-60 and women between 50-55. Risk factor assessment can be measured based on the IVUS simulation study measurement, which is the coronary artery vessel size as shown in the following Table 1, Table 2 and Table 3.

Table 1: Data table for normal men (57 yrs)

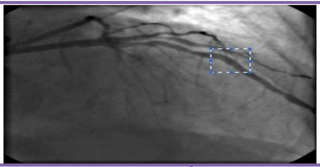
Characteristics		
Age, year		
Male (sex)		
Body Mass Index		
Vessels	Dimensions	Conditions
Aorta	30 mm	Normal
LVID	45 mm	Normal
RVID	28 mm	Normal

Table 2: Sample Case Table

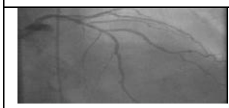
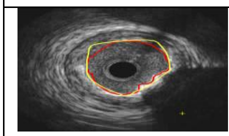
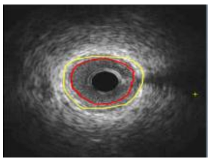
case	Difficulty	Vessel	Vessel size (Min – Max)
Stents branch	Advanced	LAD	3.25 – 4.5
Dense calcium	Intermediate	RCA	3.25 - 4.5
Distal vessel	Beginner	LAD	3.25 – 4.5

(LAD – Left Anterior Descending vessel, RCA – Right coronary Artery)

VII. LUMEN AREA MEASUREMENTS

Basic calculation of the shape parameter for adventitia-media and luminal layers are calculated (Table 3). Diameter of Mean (MD), Circular Shape Factor (CSF), Diameter Percentage (PoD) and Stenosis of luminal Area (AS) is shown in eq 4, 5 and 6.

Table 3: Sample plaque measurement

57 year man imaged after LAD stenting – (Branch Stent)	Stenosis of Lumen area	Lumen Diameter of mean	Vessel area
	Max 2.5 mm Min 2.4 mm	4.7 mm^2	12.4 mm^2
Case: Dense calcium			
	7.7 mm^2	Max 3.2 mm Min 2.8 mm	16.2 mm^2
Case: small vessel			
	4.7 mm^2	Max 2.5 mm Min 2.4 mm	7.2 mm^2

$$CSF = \left(\frac{\pi.\text{Diameter}}{\text{Observed parameter}} \right)^2 \quad \text{Eq. 4}$$

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$$\text{Diameter Stenosis} = \frac{Dm_{\text{indexes}}}{Dm_{\text{indexes}} - Dm_{\text{quanities Obtained}}} \times 100 \quad \text{Eq. 5}$$

$$\text{Area stenosis} = \frac{\text{Cross sectional area}_{\text{indexes}} - \text{Cross sectional area}_{\text{quantities obtained}}}{\text{Cross sectional area}_{\text{indexes}}} \times 10 \quad \text{Eq. 6}$$

VIII. SHAPE PARAMETER MEASUREMENTS IN IVUS IMAGE LAYERS

Shape parameter can be used for calculating the analysis of the plaque layer, which can be determined by the actual real open wall of the artery named Lumen layer. Cross sectional IVUS image layers measurements, can be defined in the following calculations as shown in eq 7, 8, 9 and 10.

Lumen eccentricity = (Lumen Layer Maximum Diameter (LLMaxD) – Lumen Layer Minimum Diameter (LLMinD)) / 100. Eq.7

Lumen area stenosis = ((Reference lumen CSA – minimum lumen CSA) / (Reference lumen CSA)) x 100. Measurement of plaque = measurement of media layer + plaque layer. Eq.8

Plaque centricity = (Maximum plaque thickness – minimum plaque thickness / maximum plaque thickness) x100. Eq. 9

Plaque burden = (plaque Area x vessel Area) / 100. Eq. 10

IX. RESULTS AND DISCUSSIONS

The proposed method defines the plaque layer through several experimental results of the IVUS coronary artery. First, initialize the contour point properly, which is one of the most important for processing an IVUS images as shown in Figure 4. This system introduces the Iterative based Energy minimization of contour method that is used to initialize the curve, that can move near towards the target for easy understanding of the object outline and get the refined value for iteratively selecting the image features for analyzing the plaque layer as shown in Figure 5.

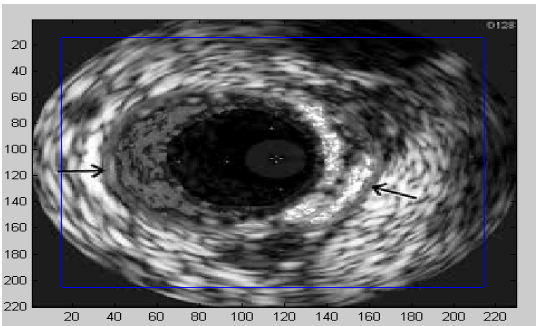


Figure 4: Initialize the contour

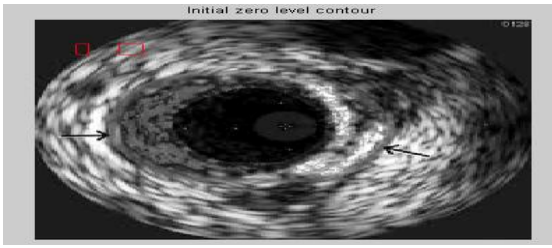


Figure 5: Initial zero level contours

Energy minimization of contour method can computes the basic shape parameters for the luminal, adventitia, media and plaque border, which detects the specified image features and also the flexible curve or surfaces which can be dynamically adapted to require the layer edges in the IVUS coronary artery image. It can be used for analysis of clinical purpose, and can meet the following critical requirements as robustness, efficiency, accuracy, low cost and complete automatization.

Various types of energy forces can be used to extricate the image features for plaque layer analysis, which will be worked out by using the iterations as shown in Figure 6 and 7.

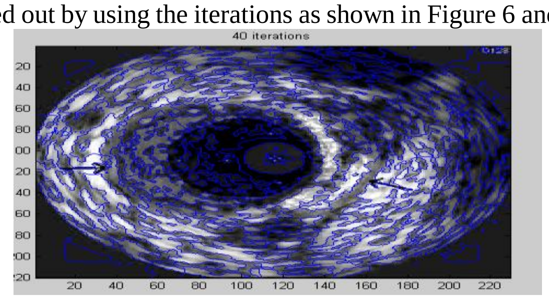


Figure 6: Iteration can be taken

Nearly thousand iterations can be used for plaque layer analysis part and also time to be taken for each iteration and the iteration graph are shown in Figure 8, 9 and 10. It can be used to identify the vessel border and also characterize the analysis of the plaque component.

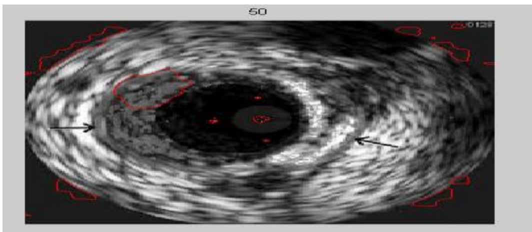


Figure 7: Next Iteration

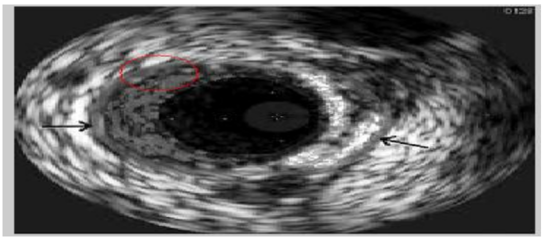


Figure 8: Plaque layer analysis

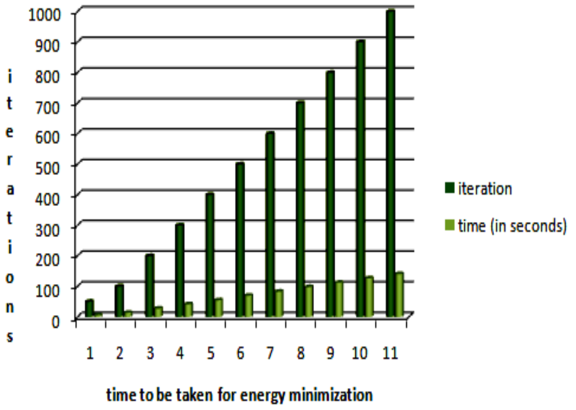


Figure 9: Iteration can be taken for energy minimization

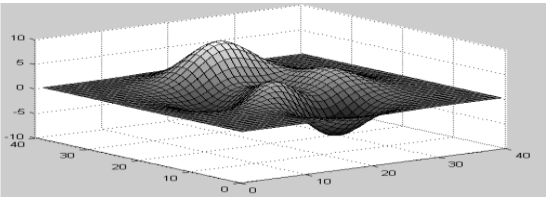
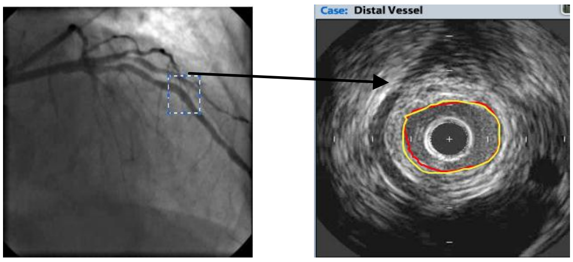


Figure 10: Iteration graph

X. COMPARISON RESULTS

Nearly 239 cases can be used for the analysis of the plaque layer, which provides the information about the shape parameter measurement for analyzing the coronary artery plaque layer. The lumen diameter measurement can be taken, which can be compared with the expert's measurement prediction as shown in Figure 11. Some of the cases can be defined using the IVUS simulator for comparing the results and are shown in the Figure 12.



Case: Distal vessel, Coronary artery vessel wall
Measurement: lumen area 4 mm^2

Figure 11: Distal vessel with the lumen layer

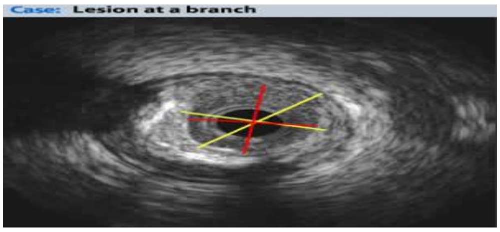


Figure 12: Lumen Diameter

Table 4 represents the proposed method evaluation through the following parameter such as True Positive (TP), True Negative (TN), False Positive (FP), False Negative (FN), Specificity and Sensitivity and the Geometric Mean (GM). Proposed IEMCM method compared with two existing algorithm and provides the betterment through the analysis and comparison graph in Figure 13 which shows the performance evaluation.

Table 4: Proposed method analysis by metrics

Selected Metrics	Region based	Clustering	IEMCM
TP	6	0	8
TN	0	5	3
FP	5	0	0
FN	2	8	2
Specificity	0.00	1.00	1.00
Sensitivity	0.75	0.00	0.80
GM	0.87	1.00	1.34

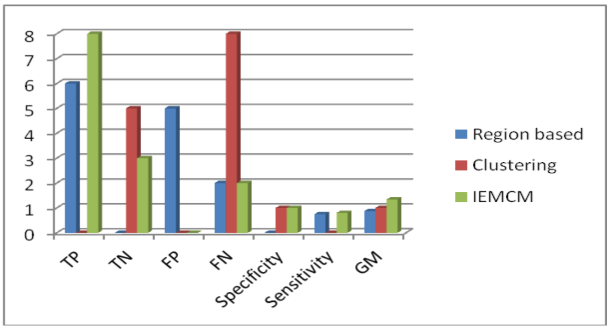


Figure 13: Comparison graph for Performance metrics

Existing and proposed method and its corresponding analysis are reported in table 5. According to that results are reported and compared with existing parameter. Proposed method obtains the accuracy level as 84.62%. All the above results are graphically shown in Figure 14.

Analysis Method	Accuracy
Region based	68.46%
Clustering	76.15%
IEMCM	84.62%

Table 5: Accuracy Calculation

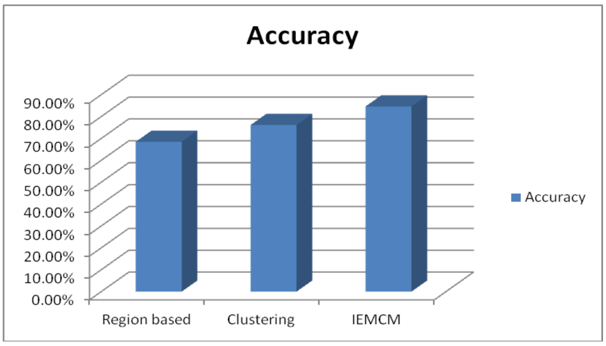


Figure 14: Graph for Accuracy

From the above results it is clear that proposed IEMCM method works better than the existing two algorithms in terms of sensitivity, specificity and accuracy.

XI. CONCLUSION AND FUTURE ENHANCEMNET

This system detects the IVUS images by using shape parameter measurements especially for lumen diameter measurement which implies the Iterative based Energy Minimization of Contour Method (IEMCM). It proves to identify the plaque layer component and also iteratively selects the image features for the above purpose. Risk factor assessment can be measured by using clinical measurements. Plaque layer identification is one of the challenging tasks in real world phenomenon. The proposed method IEMCM provides better accuracy which shows this method is an effective one. So, in future research there is a need and huge scope to improve the performance factors like Dice coefficient, Hausdorff distance, Precision, Recall, and F-measure.

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