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Classification of Plaque in Carotid Artery Using Intravascular Ultrasound Images (IVUS) by Machine Learning Techniques

K.V. Archana[1*], Dr.R.Vanithamani [2]
[1,2] School of Engineering, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India
***Corresponding Author**: archana_ece@avinuty.ac.in

ABSTRACT

The detection of plaque in carotid artery is essential to prevent stroke, cardiovascular diseases and long-term disabilities. Stroke is considered as the major cause of death these years. In this work, Intra Vascular Ultrasound (IVUS) images of carotid artery are used for classifying the plaque deposited images from the normal one. The features that are extracted from the IVUS images includes: Mean, Standard Deviation, Energy, Histogram, Entropy and Contrast. These are fed as the input to the machine learning architecture. The machine learning algorithms employed in this study are K-Nearest Neighbour (KNN), Support Vector Machine (SVM), Decision Tree and Bagged Trees. Among the four classifiers used, bagged trees showed higher accuracy of 96.2%, sensitivity of 92.6% and specificity of 96.8%.

Keywords: Plaque, Carotid artery, Machine Learning, K-Nearest Neighbor (KNN), Support Vector Machine (SVM), Decision Tree and Bagged Trees

1. Introduction

Stroke (brain attack) is considered as the fifth largest cause of death in the world and it is caused by the occlusion of artery. Occlusion refers to the blockage of the artery by fat deposits called as plaque. When this narrowing of artery due to fat deposits occurs, it is referred to as Carotid Artery Stenosis [8]. For autopsy studies, the imaging of Coronary plaque is required. Using imaging techniques, the atherosclerotic lesions are identified for diagnosing the coronary artery diseases [7]. Cerebral Infarction, Ischemic stroke and all cause of death is developed from carotid artery stenosis, if it is not properly diagnosed at the right time [9, 12]. Treatment procedure for cerebrovascular stenosis was highly aggressive consisting of surgical resection and intravascular stenting. Hence in order to avoid these procedures, early detection of stenosis is essential. To predict the prognosis of carotid stenosis, risk factors included are age, diabetes, smoking and atrial fibrillation [9].

The early detection of any disease is necessary for the preventing the high risk of damage to the tissues and internal organs. The preventive measures for coronary diseases includes dietary changes, the therapeutic measures such as lipid lowering therapy and surgical measures like stenting of the occluded artery are carried in order to prevent stroke and myocardial infarction [17]. Computer Aided Diagnosis (CAD) is useful to identify the risk of damage at a very early stage considering the patient's life style, age, pressure, family history and diabetic conditions.

In this paper, Machine Learning (ML) algorithms are used to classify the IVUS images based on the fat deposits in the coronary artery. The features that are extracted are fed to the classifier for efficient classification of images for identifying the plaque deposition. A dataset of 99 IVUS images are taken for analysis. 79 images are used for training and 20 for testing. Classification algorithms such as K- Nearest Neighbor (KNN), Support Vector Machine (SVM), Decision Tree and Bagged Tree algorithms are tested. Features extracted includes: Mean, Standard Deviation, Contrast, Entropy and Energy. Evaluation metrics used for analyzing the performance of ML algorithms include sensitivity, specificity and accuracy.

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1.1 Anatomy of Carotid Artery

The major blood vessels which supply blood to the brain, neck and face is the carotid arteries. Carotid artery branches into two portions in the neck, namely internal carotid artery and external carotid artery. The internal carotid artery supplies the blood to the brain and external carotid artery supplies blood to the face and neck [8]. Like majority of the blood vessels running inside the body, carotid artery also has three layers namely

- Intima, the innermost smooth layer
- Media, the middle muscular layer
- Adventitia, the outermost layer

The pulse from the carotid artery can generally be felt in the region around the neck [8].

1.2 Atherosclerotic Plaque

Heart and blood vessel diseases are mainly caused due to the plaque deposition in the layers of carotid artery. Calcium, Cholesterol, fat and various other substances are responsible for the development of plaque in the arteries [11]. Hence early detection of plaque deposition is necessary to diagnose diseases such as stroke, myocardial infarction and other coronary heart diseases.

This paper is structured as follows: Section 2 discuss about the related works done in classifying IVUS images, Section 3 details about the overall workflow, Section 4 summarizes the classification algorithms used in the analysis, Section 5 gives the experimental results and Section 6 concludes the paper.

2. Literature Review

Tae Joon Jun et al., 2019 proposed a method to classify Thin-Cap Fibroatheroma (TCFA) using machine learning techniques such as Feed forward Neural Network (FNN), Convolutional Neural Network (CNN), Random Forest (RF) and k-Nearest Neighbours (KNN). To reflect the physicians TCFA discrimination, a pixel-based feature extraction is proposed. The vessel properties namely necrotic core and the calcified nodule is differentiated based on the brightness of the pixel. 12,000 OCT images are used for this study [1].

Hengfei Cui et al., 2020 has used a supervised machine learning method for the segmentation of coronary arteries with minimal user interaction. The framework of gradient boosting along with the quadratic approximation is also implemented. This system achieved a Jaccard similarity of 96.8% implying that it has reached a higher accuracy when compared to other learning methods. The final prediction of data is done using real time images [2].

Fengjun Zhao et al., 2019 proposed an automated multi-class detection and classification of coronary plaque. The transverse cross section along the centerlines of the artery wall is retrieved from the Computer Tomography (CT) images. Coarse segmentation is performed to extract the Region of Interest (ROI) of the image. Multi class classification of coronary plaque is done using Random Radius Symmetry (RRS) feature vector extraction. The precision of the system is 92.6 ±1.9% by using RRS and Support Vector Machine (SVM) [3].

Paulo G P Ziemee et al., 2020 proposed an automated gating algorithm to select end-diastolic frames and to bypass the saw tooth artifacts in the first stage. During second stage the automatic segmentation of the lumen in the image is done using multi frame CNN. The theory of Gaussian process was applied to the lumen boundary in the final stage to return to the former or the less developed state. This proposal reduced time in manual delineation and cost [4].

Hannah Sofian et al,2015 presented an automated segmentation method to segment the outer boundaries of the layers of an artery. The plaque deposited in the arteries walls imposed the problem in segmenting the layersof the arteries. Otsu thresholding method is used for the segmentation followed by binary-morphological operation. Ten samples from the dataset were utilized in this study [5].

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Latha et. al, 2020 provided a widespread review on different pre-processing, segmentation and classification techniques for carotid artery ultrasound images. Using machine learning techniques, the images are classified based in the plaque deposition in the arteries. The machine learning techniques that are implemented includes: SVM, KNN and Self Organizing Maps (SOM). The three layers of the artery are discussed in detail along with the formation of plaque. A review on different denoising algorithms along with the order statistics highlighting the evaluation criteria is discussed. The study concluded that the CAD procedure is effective in the identification of plaque in IVUS image. For real-time approach fully automatic segmentation and classification was preferred [6].

Daniel Bos et al, 2021 discussed that the composition of plaque is important compared to the size of the plaque because it is linked to ischemic cardiovascular events. For imaging, carotid artery bifurcation is easily accessible. It plays a major role in the developmental onset of ischemic stroke. Due to the small size in the arteries and cardiac motion, the imaging of the wall is complicated. The composition of atherosclerosis in the carotid bifurcation showed a higher correlation in the formation of plaque inthe carotid arteries. The stroke is assessed by previous medical histories and through continuous monitoring. The study is conducted with a population of 2666 participants who underwent Carotid Magnetic Resonance Imaging (MRI) examination. In the assessment, the result obtained is categorized based on the Carotid plaque characteristics, presence of coexistent components and plaque size [18].

3. Materials and Methodology

3.1. IVUS Image Database

Dataset of IVUS images of Common Carotid Artery (CCA) is obtained from publically available database [13]. It consists of 99 images in which 79 images are used for training and 20 images for testing. IVUS images are selected for the following reasons,

- It has elevated border in media – adventitia.
- The adventitia tissue is extremely vivid.
- The lumen section is harmonized and is not complicated.
- The concentration of the lumen boundary is elevated; it is useful for the extraction of features and also for segmentation.

A sample IVUS image of coronary artery is shown in Figure 1.

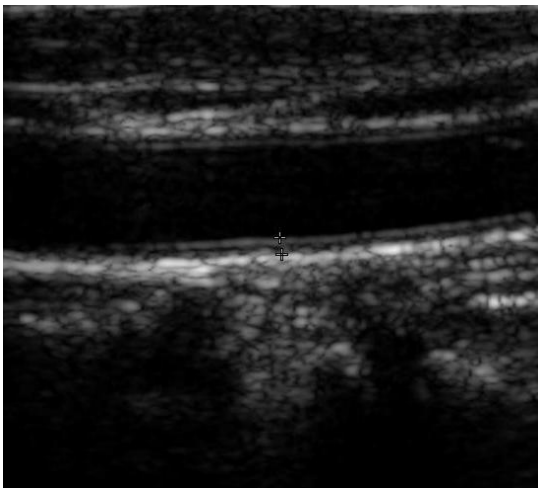

Figure 1: Sample IVUS Image

Figure 2 shows the block diagram of the proposed method. The overall work focuses on classifying the IVUS image dataset based on the plaque deposited on the artery walls. The work flow consists of three stages: In the first stage, features such as Mean, Standard Deviation, Contrast, Entropy and Energy are calculated. Second stage, is classifying the images using Machine Learning techniques such as KNN, SVM, Decision Tree and Bagged Tree. The third stage

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is analysing the performance of the classifier by means of evaluating performance metrics such as accuracy, sensitivity and specificity.

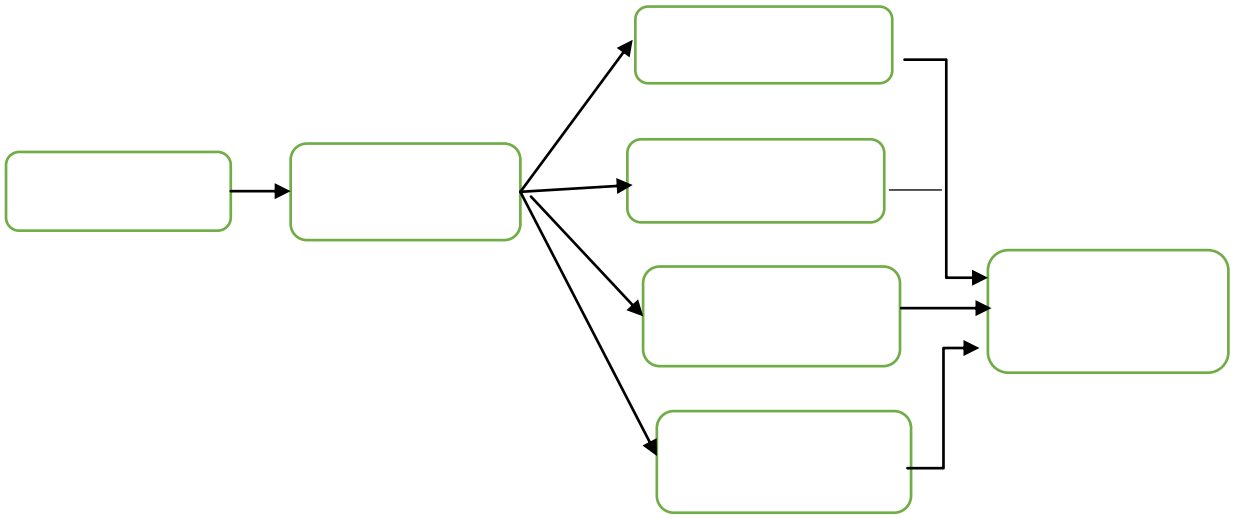

Figure 2: Block Diagram of Proposed Method

3.2. Feature Extraction

The features that are extracted from the image must be non-redundant and carry necessary information for the classification process. The feature selection is performed after selecting the feature vectors. A large number of feature vectors can lead to misclassification of the images. Hence efficient selection is needed for better accuracy of the classification of images. The textural features such as mean, standard deviation, contrast, entropy and energy are extracted. The derivative equations for the features are formulated in Table 1.

Table 1 Derivative equations

Features	Equations
Mean	$= \frac{1}{NM}\sum_{x=1}^{N}\sum_{y=1}^{M}\left\|D_j(x,y)\right\|$
Standard Deviation	$\sigma_i = \frac{1}{NM}\sum_{x=1}^{N}\sum_{y=1}^{M}\left\|D_j(x,y) - \mu_i\right\|^2$
Contrast	$\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}\|x - y\|^2\, p(x,y)$
Entropy	$\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} p(x,y)\, log\big(p(x,y)\big)$
Energy	$\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} p(x,y)^2$

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4. Classification

This section briefly explains about four classification networks that are used in this work. The architecture and the confusion matrix of the classifiers are as follows.

4.1 K-Nearest Neighbor (KNN)

The flowchart of KNN is shown in Figure 3. In this technique, the classification of images is done by selecting the k point in the neighboring pixel values. This algorithm is more sensitive to the local information of the image dataset. Multi feature classification system has proven efficient in the classification of medical images [6].

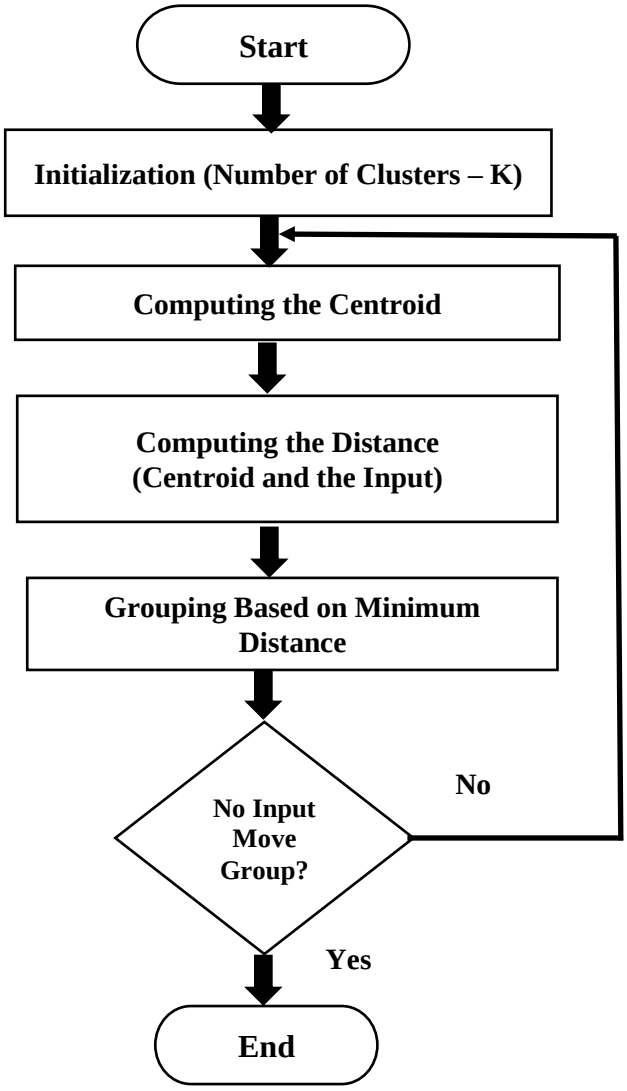

Figure 3: Flowchart of KNN Classifier

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4.2 Support Vector Machine (SVM)

In this model a hyperplane is identified and it divides the images into two categories. They are highly efficient for binary classification. SVM is a supervised non-linear model. The ability to work with a large feature vector space makes this algorithm inevitable in the classification. This model was suitable for the detection of hard and soft plaque because of better fittingcharacteristics [6]. Figure 4 shows the two classification maps along with the hyperplane.

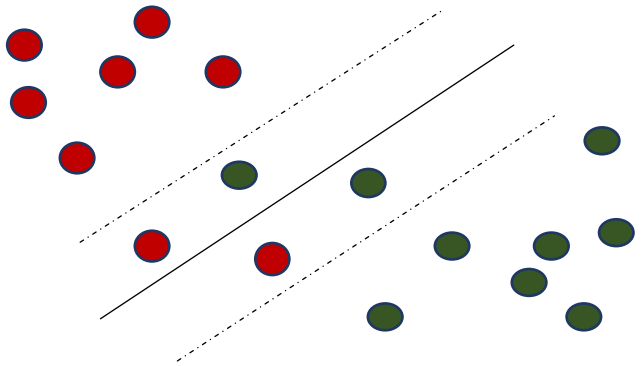

Figure 4: Classification using SVM classifier

4.3 Decision Tree

Decision tree is the prominently used algorithm in data mining for classifying the data into predefined sets. The architecture of decision tree is illustrated in Figure 5, where the root is at the top and the architecture branches as a decision rule. The classes are represented as each leaf nodes [14].

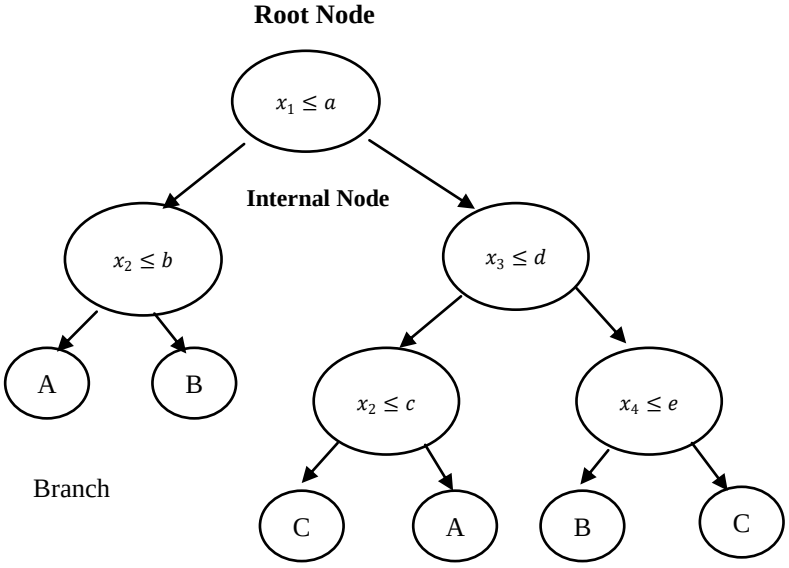

Figure 5: Architecture of Decision tree

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4.4 Bagged Trees

A bagged tree is a high variance machine learning algorithm. It is a Random forest algorithm in which different training models can be created from a single dataset. Instead of depending on a single output as in decision tree, a greater number of outputs can be acquired from the bagged trees. This algorithm is useful for the classification of plaque deposition from IVUS images. The bagged tree structure is considered as a bag of decision tree algorithms. The architecture of bagged trees is shown in Figure 6.

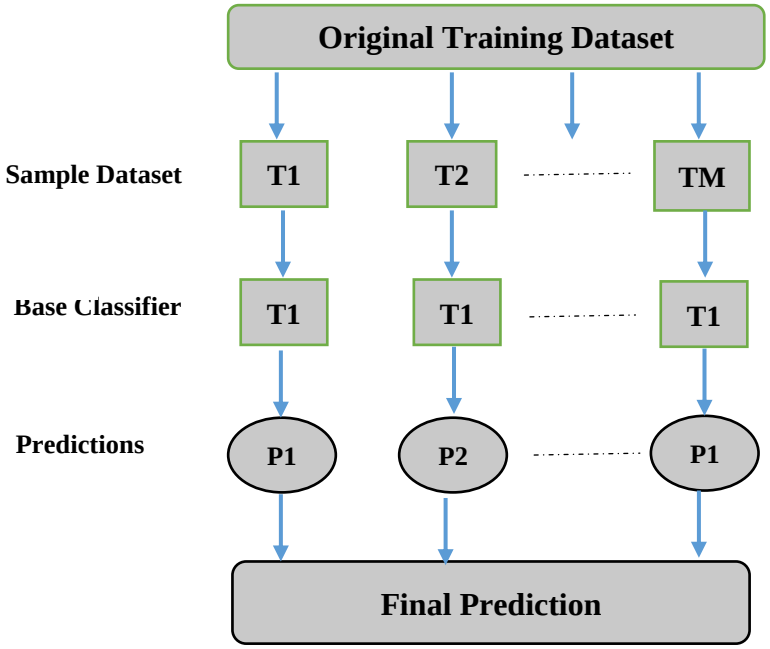

Figure 6: Architecture of Bagged tree

5. Results

The IVUS dataset of 99 images are taken for the classification. The features that are extracted includes Mean, Standard Deviation, Entropy, Contrast and Energy. Based on these features, the classifiers are trained with a dataset of 79 images. 20 images are used for testing. Table 2 shows the values of the features that are extracted from IVUS image dataset used for testing the classifier.

Table 2 Features Extracted

Test Images	Mean	Standard Deviation	Entropy	Contrast	Energy
Image 1	20.08	37.49	4.75	0.34	0.63
Image 2	22.64	41.07	5.16	0.34	0.62
Image 3	18.43	37.03	4.53	0.34	0.66
Image 4	19.32	37.61	5.00	0.35	0.68

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Image 5	26.86	41.91	5.45	0.36	0.53
Image 6	29.67	44.24	5.89	0.34	0.52
Image 7	29.23	42.96	5.82	0.35	0.51
Image 8	21.04	38.92	4.95	0.35	0.63
Image 9	18.45	37.24	4.52	0.33	0.66
Image 10	19.12	37.13	4.98	0.34	0.68

The extracted features are used for classifying the images into plaque deposited or normal one. The performance of the classifier is evaluated by calculating the sensitivity, specificity and accuracy of the classifiers.

- Sensitivity is the likelihood of the event that will be detected. The sensitivity equation is given below

$$Sensitivity = \frac{TP}{TP + FN} \quad (1)$$

- Specificity is the probability that the absence of the event getting identified. The equation of specificity is,

$$Specificity = \frac{TN}{TN + FP} \quad (2)$$

- Accuracy is the measure to check the functionality of a classifier.

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} \quad (3)$$

Where *TP* is True Positive,
TN is True Negative,
FP is False Positive and
FN is False Negative

Table 3 shows the values of the performance metrics, calculated using the equation (1) to (3).

Table 3 Performance Metrics

Machine Learning Algorithm	Accuracy	Sensitivity	Specificity
Support Vector Machine	91.1	83.33	95.39
K-Nearest Neighbor	96.2	91.26	96.37
Decision Tree	88.6	82.39	86.42
Bagged Trees	96.2	92.6	96.89

The performance of the classifiers is shown in the Figure 7. Of the four classifiers used, bagged trees showed higher accuracy of 96.2%, sensitivity of 92.6% and specificity of 96.8%.

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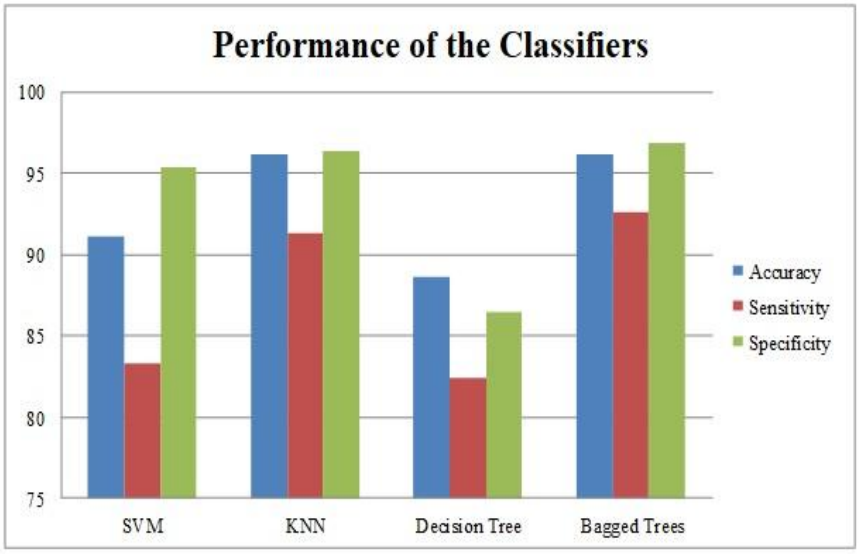

Figure 7: Performance of the Classifiers

6. Conclusion

Thework aims in implementing four computational techniques for classifying the carotid artery images for identifying the plaque deposition. IVUS dataset consisting of 99 images are used for the analysis. Initially significant feature vectors for classifying the images are selected and extracted from the image. These data are used for classification using four machine learning algorithms such as KNN, SVM, Decision Tree and Bagged Tree. The performance metrics used for evaluating the classifier are sensitivity, selectivity and accuracy. Among the four classifiers used, bagged trees showed higher accuracy of 96.2%, sensitivity of 92.6% and specificity of 96.8%. The early detection of the plaque formation in the arteries are vital for assisting the radiologist in identifying atherosclerosis and stroke. Thus, the Computer Aided Techniques will be more efficient and fast analyzing method in supporting the diagnosis of coronary artery diseases.

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