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Intra-Vascular Ultrasound Image Based Decision Support System For Coronary Plague Classification

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Abstract

Heart attacks continue to be one of the most common reasons for increasing mortality now-a-days. Intra-Vascular UltraSound (IVUS) imaging has recently been used in the development of a variety of classification methods for the plaques that are seen in the coronary arteries. Plaque analysis is an important tool for early detection of coronary artery disease, which may have devastating consequences. A powerful decision support system (PDSS) for the plaque categorization using IVUS image is presented in this paper. Multi Directional Transform (MDT) is employed for extracting features and Maximum Likelihood Classifier (MLC) is employed for the classification. In order to remove the speckle noise from the given IVUS image, a preliminary processing step is performed on it. After the preprocessing step has been finished, the proposed system will extract features using MDT, and it will then classify the IVUS images as either normal or abnormal. Based on the results of the evaluation of the proposed system, it seems that the classification of IVUS images may be accomplished exclusively by the extracted texture features, and that the accuracy of the classifier is dependent on these derived features. It has been shown that the system produces a satisfactory outcome, with a sensitivity of 98%.

Keywords

Plaque categorization, image classification, heart attack, computer aided diagnosis, decision support system.

Imprint

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1. INTRODUCTION

The heart, blood, and blood vessels are the primary components of Cardio Vascular System (CVS). The movement of waste products, glucose, oxygen, amino acids, and other nutrients and medications to and from the various tissues of the body is the primary purpose of this system. Another function of this system is the movement of oxygen to and from the lungs. Additionally, the CVS is involved in the modulation of hormones as well as the regulation of temperature inside the body. The left and right ventricles, which both function as pumps, are located in the heart. The right side of the heart is responsible for pumping deoxygenated blood to the lungs, while the left side of the heart is responsible for receiving oxygenated blood from the lungs and pumping it to the rest of the body through the aorta. Both sides of the heart are connected by the aorta. The inferior and superior vena cava brings deoxygenated blood from the body to the right side of the heart, which then pumps it to the rest of the body. The coronary arteries are responsible for delivering oxygen-rich blood to the tissues of the heart. In most people, the aorta divides into two coronary arteries—the right and the left—which then form branches surrounding the heart.

Atherosclerosis is the accumulation of fatty substances (lipids), cholesterol, calcium, or fibrous material in the lining of an artery. This may lead to a variety of health problems. It is possible for this condition to impair the arteries of the kidneys, heart, brain, and other essential organs. Plaque development in the coronary arteries of the heart may cause the arteries to narrow, which in turn reduces the amount of oxygen that can reach the heart muscle. This can cause the oxygen supply to the heart muscle to decrease during times of increased stress. This may either cause harm to the heart or lead to abnormal functioning of the heart. Angina, sometimes referred to simply as chest discomfort, is frequently the first indication of coronary artery disease. Atherosclerosis may be harmful because it can gradually or abruptly, during a rupture, clog the arteries or weaken the walls of the arteries. Either way, this can result in damage. At the site of the plaque, thrombosis might develop, which increases the risk of myocardial infarction (heart attack).

The organization of this article is as follows: The information on the several IVUS image classification methods are given in Section 2. Section 3 discusses the design of the MDT-MLC based IVUS image categorization system. The findings of the proposed MDT-MLC system for IVUS image categorization are presented in section 4. The conclusion of this work and suggestions for further research, are presented in section 5.

2. RELATED WORKS

Dong et al. (2021) addressed the segmentation of the coronary lumen and the exterior elastic membrane in IVUS images. In order to circumvent the issue of overfitting, the data augmentation approach is used. In order to increase the model performance without resorting to pre-processing or post-processing of the raw IVUS images, the mesh-grid method is used in conjunction with the flip and rotation procedures. The produced u-net is used in the cross-sectional area to partition the coronary artery lumen and the region that is surrounded by the exterior elastic membrane. Images of coronary arteries may have their coronary lesions, stenosis, and atherosclerosis plaques automatically accessible.

In the cardiac catheterization lab, the side-viewing IVUS images are employed often. However, this technique can only be used to assess blood flow in big channels at this time. Collins et al. (2020) provided an explanation on the singular value decomposition filtering that was used for the microvasculature grayscale showing blood flow in tiny arteries. Imaging with IVUS reveals the presence of neovascularization, which indicates that there is a potential for a reduction in the risk of rupture in the coronary artery. While the patient is receiving diagnostic catheterization, it is possible for it to be of adequate assistance in the preceding therapy for patients who have stable coronary disease.

Charanya et al. (2020) provided an explanation of the unique feature extraction method for the regression process of an IVUS image as well as the stochastic gradient descent strategy for detection. The athermanous plaque lumen amount in coronary arteries is evaluated using this categorization method, together with the atheroma that is concealed inside the arterial wall. In addition, the frequency domain feature extraction approach performs qualitative analysis of the IVUS images using the stochastic gradient descent method for the purpose of performing efficient classification.

Dr.S.Hemachandra et al. (2020) developed a methos for processing ECG (Electrocardiogram) signal. This signal plays an important role diagnosis and analyzing the heart abnormalities. Wavelet transforms are used to increase the visibility in the graphical representation of the ECG signal.

The article by Cao et al. (2020) discussed the multi-parametric features of the vascular lumen, tube wall, and athermanous plaque that were retrieved from the cross sectional image of the IVUS of the coronary artery. This time-consuming and labor-intensive pre-processed noise reduction framework adaptation assists the cardiologist in analyzing and diagnosing coronary heart disease in preparation for surgical therapy. Utilizing DeepLab v3intima +'s and adventitia structure provides an additional benefit, which is the automatically achieved standardization of clinical parameters that are significant to medical practice.

Sridevi and Sundaresan (2020) provided an explanation for the IVUS image classification that is based on the Modified Radial Basis Function Kernel (MRBFK) learning with the SVM classifier (2020). Calcium buildup in atherosclerotic plaques is the primary contributor to deaths caused by coronary heart artery disorders. A particular phase SVM classifier is used in order to make a prediction about the atherosclerotic plaque IVUS images. In order to get the information specifics necessary for categorization, the special procedure is used. After that comes the extraction of the most fundamental features, the classification of the IVUS image, and the analysis of the results using an MRBFK-based SVM classifier.

Oosterveer et al. (2020) addressed the intracoronary imaging approach that is used for IVUS and OCT images. The coronary angiography in the coronary artery utilizing the intravascular ultrasound (IVUS) imaging modality is used for the evaluation of the CAD system. PCI guided by intracoronary imaging is a technique that assists in evaluating coronary artery disease (CAD) with coronary artery stenosis and the intraprocedural method of coronary arteries. This helps overcome the limitations that are associated with utilizing IVUS alone.

Eslami et al. (2020) examined the morphological existence of coronary atherosclerosis in modeling CT as well as its composition. A large plaque volume, low CT attenuation, spotty calcification, and remodeling of the computational fluid dynamic system of blood flow through the coronary arteries are the CT high risk-rupture lesion characteristics of anatomic and hemodynamic plaque features. These characteristics indicate a higher likelihood of a plaque rupture. Modeling components for computational fluid dynamics need image-based anatomy with boundary and blood property or rheology-based mesh creation.

Myocardial infarction without obstructive coronary artery disease is a substantial cause of death and morbidity, as was highlighted in Alasnag et al (2020).'s explanation of the diagnostic and risk management of the condition. The majority of individuals have their coronary arteries examined using the traditional approach of coronary angiography during their first cardiac tests. Intracoronary imaging with more accurate pathological knowledge, such as that provided by OCT or IVUS images, enables location or geographic assertions to be made using cardiac magnetic resonance imaging.

Radio-frequency measure of IVUS imaging was used by Xie et al. (2020) to define the coronary plaque tissue of individuals with early coronary artery disease. When compared to the coronary risk factors of later-stage coronary artery disease, those of premature coronary artery disease show a greater prevalence of fibrotic lesions and a lower proportion of necrotic and calcified components. The IVUS imaging characteristics of coronary plaque tissue associated with the first occurrence of angina or myocardial infarction for the patients of the department of cardiology received a considerably lower range of atherosclerosis.

Jamthikar et al. (2020) provided an explanation of the non-invasive carotid ultra-sonography method that is used for the evaluation of the risk of cardiovascular disease and stroke. In the medical field, the automated computational paradigms such as ML and Deep Learning (DL) approaches with carotid and coronary ultra-sonography are used to evaluate the risk of cardiovascular disease or stroke. Patients may reduce their chance of having a stroke or cardiovascular disease by employing both traditional and integrated machine learning algorithms, which make use of a variety of data-driven factors.

Shan et al. (2020) provided a comprehensive study of the tissue categorization of IVUS imaging in the human body. There are several imaging modalities in the medical field, including computed and positron emission tomography, in addition to magnetic resonance and ultrasound imaging. The IVUS image is considered to be the most effective and popular modality because to its low cost, absence of harmful ionizing radiation, and ability to provide real-time, convenient procedures. The method of signal analysis is used in the process of extracting the distinctive characteristics. A machine learning approach is used for pattern recognition, while classification methods are utilized for classifiers. Image pixel categorization is made easier by CNN-based deep learning techniques.

Gresele et al. (2020) provided a comprehensive analysis of the process of risk assessment in patients with asymptomatic cardiovascular carotid artery atherosclerosis. Antithrombotic medications are used in the treatment of asymptomatic carotid atherosclerosis in people who have coronary artery disease. Patients who have this condition also take aspirin. The use of aspirin as a primary preventative in these individuals continues to be a challenge for medical professionals, although it may be approximated using risk variables for cardiovascular disease and bleeding.

Wang et al. (2020) used OCT and angiography data imaging to construct a patient-specific circumstances stress based coronary artery model. This model is produced by employing patient-specific conditions. The OCT-based fluid–structure interaction model is used in order to evaluate the plaque ruptures that are associated with the occurrence of mechanical stress. The structure of the lumen, the arterial wall, and the plaque components make up the rebuilt patient-specific model of the coronary artery. This fluid–structure interaction model with regions of low WSS helps locate places that have increased plaque susceptibility. This is because when pressure is applied on the flexible artery, the fluid domain has the potential to expand circumferentially.

Liu et al. (2020) offered a technique for detecting fibrous plaque in coronary arteries that is based on deep learning using CNN. The discovery of the formation of fibrous plaque is a clinically crucial step that progresses toward the beginning of the diagnostic process and therapy for coronary heart artery disease. Vascular stenosis and thrombosis are two hallmarks of heart artery plaque that are created by fibrous plaque. This fibrous plaque follows the contraction route to capture the context, and a symmetric path expansion permits the accurate localization of the disease.

Cong et al. (2020) studied the impact of malformation on the right coronary artery that originates from the left sinus in the context of the hemodynamic environment. One of the atypical origins of the coronary arteries is when the right coronary artery originates from the sinus of the left coronary artery. This is known as the anomalous origin of the right coronary artery. This has the potential to produce very uncommon repercussions on the human body, including abrupt death or indications of myocardial ischemia. A comparison is made between the alterations in hemodynamics that occur at the origin of the right coronary artery and those that occur at the anomalous origin of the right and left coronary arteries. It is possible that the symptoms of ischemia will be brought to light by the cross-sectional area of the left coronary artery inlet.

The authors Fedewa et al. (2020) highlighted how a CAD system that uses artificial intelligence (AI) in intracoronary IVUS imaging may enhance both the comprehension of the problem and the treatment of it. In order to accelerate the development of AI, improved diagnostics and workflows that make use of image segmentation, plaque analysis, and stent assessment are necessary. This machine learning technique, which is employed in data analytics and digitalized medical imaging (specifically, in IVUS and OCT images for intracoronary arteries) gives a better knowledge to enhance results and save expenses.

V.Vijaya Kishore et al. (2020) developed a method for detecting malignant nodules from the medical image. They have elaborated on the critical task as the image may contain noise during the processing that can be unseen and also having similar intensities of unwanted tissue thickening.

Quantification of coronary plaque cap thickness and plaque susceptible IVUS image was investigated by Lv et al. (2020) using OCT imaging. This imaging approach is used in the process of doing IVUS image-OCT based CNN segmentation. The data on the cap thickness are retrieved in order to assess the variations between the measures obtained from the IVUS image and the OCT image. In order to demonstrate that this study is successful, larger-scale patient trials are required.

The tools for integration of segmentation, extraction and classification of images is developed by V.Vijaya Kishore (2022). Hospital Information System (HIS) and Picture Archiving and Communication Systems (PACS) using digital entities to maintain medical examinations, images and statements.

Madhu, G. C et al. (2022) designed a method for segmenting low contrast images. They identified that this is a critical part of medical image processing. Early detection of abnormalities is critical for enhancing treatment options and boosting the overall survival percentage of patients

3. METHODS AND MATERIALS

The ability to conduct diagnostic procedures that do not need the use of intrusive techniques makes medical imaging an essential component of the modern healthcare system. The process involves developing graphical and operational representations of the internal structures of the human body and organs for the purpose of clinical investigation. Among the many kinds are x-ray-based methods such as conventional x-ray, molecular imaging, computed tomography, IVUS, and magnetic resonance imaging. In addition to the many different types of medical imaging technologies, the use of clinical images in diagnostic processes is growing. The rise in the usage of machine and deep learning approaches may be attributed, in part, to the development of faster central processing units and graphic processing units, as well as an immense number of data, and advancements in learning algorithms.

To determine which parts of a image are unhealthy and which are healthy, a conventional machine learning–based image classification system is often used. Many image classification methods are discussed by Afra Hussaindeen (2022) for skin cancer, Bakare et al (2021) for oral cancer, and Ramitha and Mohanasundaram for pneumonia classification. The standard medical image classification system is shown in Figure 1. This system includes the preprocessing, feature extraction, and classification phases of medical image

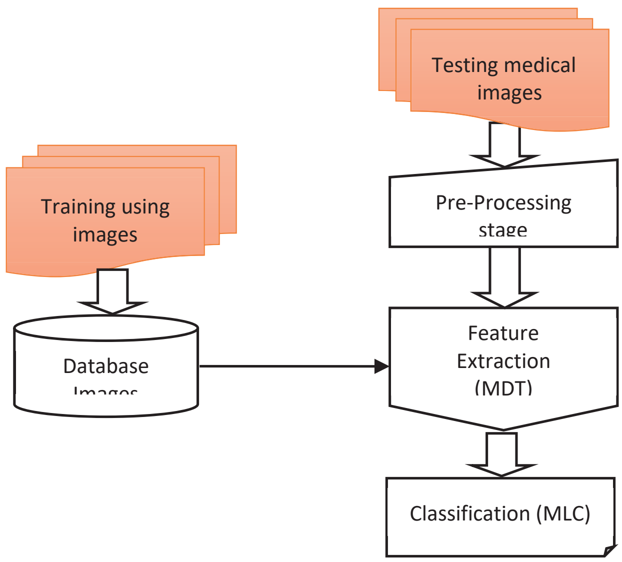

Figure 1. Flow of a typical categorization system

classification. During the phases of training and testing, the system makes use of the database images by applying a variety of classifiers to them. The initial phase in the process of developing such an application is known as pre-processing, and it involves removing any noise that may exist as well as enhancing contrast, which may include the use of a filter.

3.1 Preprocessing

The Frost filter is designed to maintain the edges of an image while at the same time reducing noise based on the local statistical data included in a sliding window. It is an exponentially damped, circularly symmetric filter that makes use of local statistical information. The level of smoothness produced by the filter is primarily controlled by a damping factor that is exponential in nature. When the damping factor is low, the image often has a smooth appearance.

It performs the functions of a median filter and strikes a healthy balance between the mean filter and the all pass filter. The construction of an exponentially curved filter kernel that may adaptively vary from a mean filter to an identity filter is the means by which equilibrium can be obtained. The different denoising capabilities may be attributed to the changes in the coefficients. When high coefficients are used in the analysis, the sharp characteristics of the images that have been provided are not averaged out. The filter design is as follows:

$$a^2 = s^2 / z^2 \tag{1}$$

$$[m(t)] = e^{-Ka^2[t]} \tag{2}$$

$$y(t) = \frac{\sum_i m(t_i)x(t_i)}{\sum_i [m(t_i)]} \tag{3}$$

where *x(t)* and *y(t)* represent the original and replacing pixel value at *t* (pixel coordinate). s^2 (image variance), z^2 (mean), *t* (pixel coordinate) and *m(t)* (weight factor). The damping rate is controlled by the parameter *K*.

3.2 Feature Extraction

Because the features that are obtained from one process directly influence the effectiveness of another process, feature extraction is regarded as an essential step in all methods of machine learning and pattern recognition. This is due to the fact that the features obtained from one process directly influence how well another process classifies data. Additionally, it is described as the first stage of intelligent image analysis, which has the tendency to eliminate redundant data and possess more intrinsic content of the original data. This stage is characterized by the fact that it has more of the original data. As a result, the work of extracting features places greater emphasis on the important visual information. This study uses MDT for feature extraction.

According to Do and Vetterli's [2005] explanation, the MDT is made up of a filter bank that has been iterated twice. The Laplacian Pyramid (LP) is first applied to the image in order to identify any point discontinuities, and then a Directional Filter Bank (DFB) is employed in order to connect those point discontinuities into linear structures. The fundamental concept that underpins this method of image analysis is the use of a transform that is similar to a wavelet in order to identify the contour segments of an image, and then the application of a local directional transform in order to identify the edges of an image. MDT offers an image expansion that makes use of fundamental components such as contour segments. The ability of the MDT to efficiently approximate a smooth contour at multiple resolutions is made possible by the fact that MDTs have elongated supports at various scales, directions, and aspect ratios. This is a characteristic that can be considered an advantage of MDT. When compared to other transforms such as the wavelet transform, it needs a far lower number of descriptors to accurately portray smooth curves, making it an excellent choice for images that include such curves. In addition to this, it offers multi-scale and directional decomposition in the frequency domain. A quick and flexible transformation may be achieved with the separation of directed and multi-scale decomposition phases; however, this comes at the cost of some redundancy caused by the LP. Figure 2 shows the MDT.

3.3 Classification

The maximum likelihood classification method begins with the presumption that the statistics pertaining to each class within each band are normally distributed, and then proceeds to compute the chance that a particular pixel in question belongs to the category in question. All of the pixels will be categorized unless you choose a specific probability threshold (Rajan 2018).

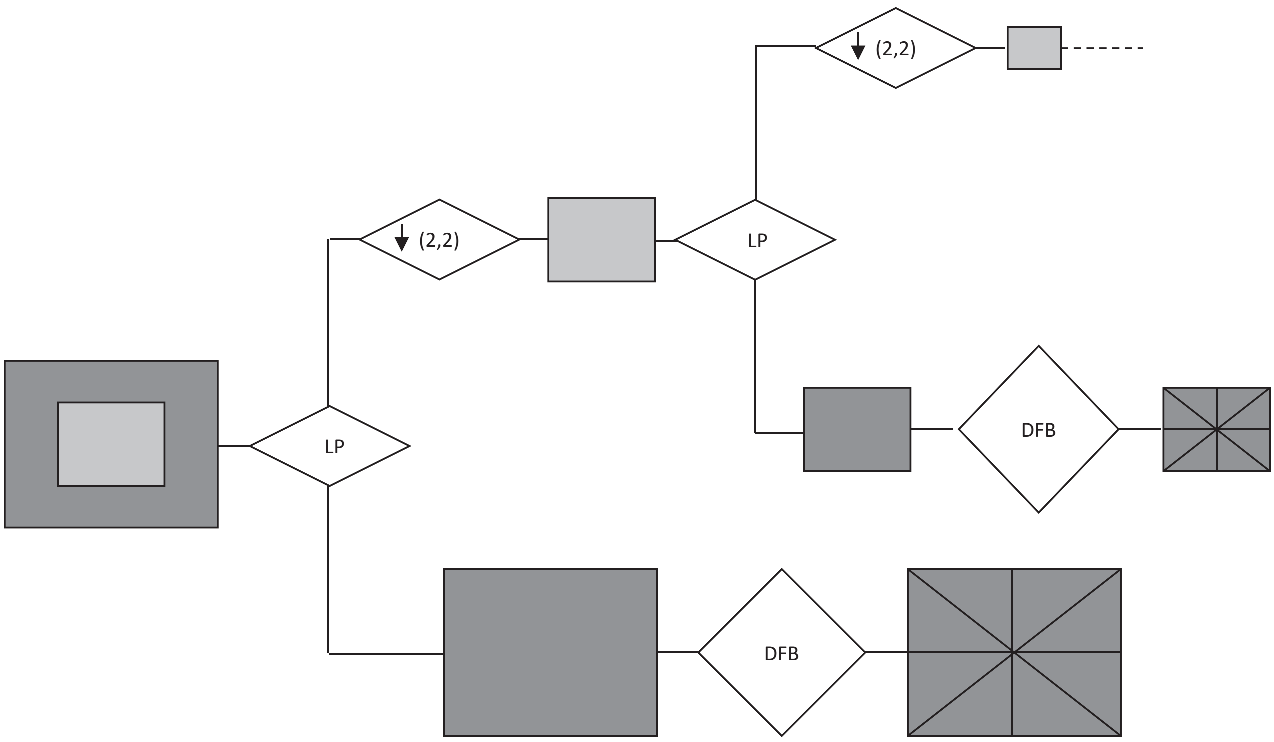

Figure 2 Decomposition Process of MDT

MLC is mainly used in the classification of remote sensing, and additionally utilized in other fields such as texture classification and tunnelled traffic with the maximum likelihood pixel value and classified into the appropriate class. It is. If all pixels are classified in the probability threshold, then each pixel is assigned to the class with the highest probability. In the event that the threshold is higher than the greatest likelihood, the pixels will not be categorized.

4. RESULTS AND DISCUSSIONS

The IVUS image of coronary artery disease is the catheter-based model that is used most often in the medical industry. The IVUS imaging are collected during a cardiac catheterization by employing ultrasound probes that are positioned on the tip of a coronary artery vessel catheter. The interaction between the various tissue structures of an artery produces a high reflection of the ultrasonic waves that have been emitted. During angiographic operations, the IVUS image is analyzed in order to get further, more specific information about calcified, necrotic, fibrous, and fibro fatty morphological plaques. The IVUS images used by Swarnalatha and Manikandan (2020) are used in this study for performance analysis. All of the images are annotated by seasoned cardiologists, and this information serves as the ground truth for the performance rating. Figure 3 shows sample IVUS normal and abnormal images.

At the preprocessing step, the normal and abnormal IVUS images are given to de-noise them and eliminate speckle noise. The images with the noise removed are processed in order to extract MDT features, and it contains a key parameter, decomposition level whose value varies from 1 to 6 in order to provide a more accurate assessment of performance. After that, these characteristics are saved in the database that stores features. MLC is used in the categorization process. Table 1 shows the performance of the MDT-MLC system for IVUS image categorization.

Table 1

Performance of the MDT-MLC system for IVUS image categorization

MDT	Classification Accuracy (%)	Execution time (seconds)
1	78	6.17
2	84	7.04
3	94	8.14
4	98	9.56
5	96	11.41
6	92	13.25

It can be seen from the Table 1 that the classification accuracy improves as the MDT decomposition climbs higher, all the way up to 4. At a crucial MDT-level of 4, the classification accuracy is maximized to its full po-

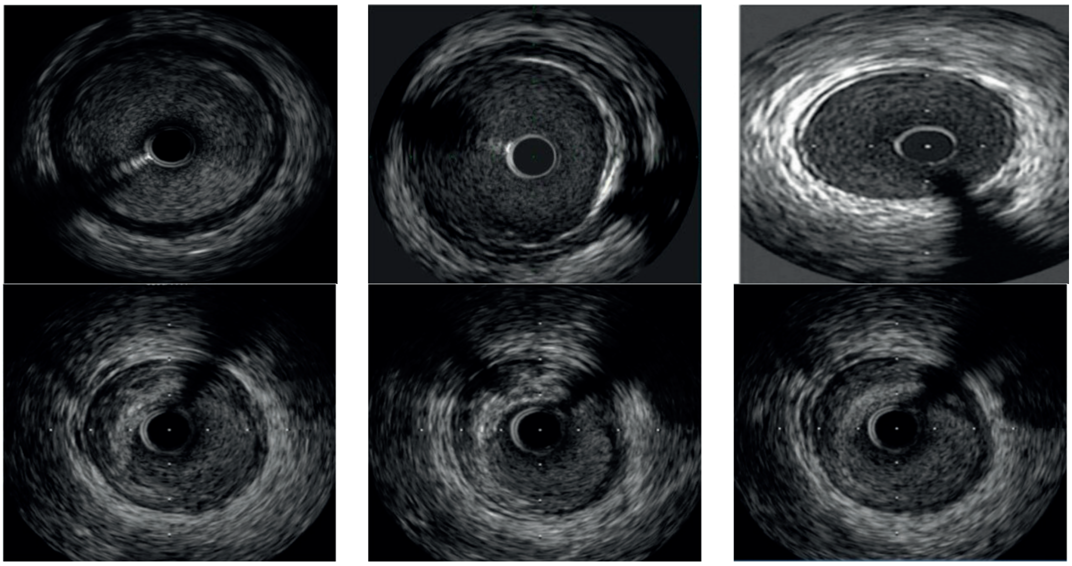

Figure 3 (a) Normal (b) Abnormal

tential, coming in at 98%. A decision may be reached in 9.56 seconds on average.

5. CONCLUSION

Images obtained from IVUS are often used in the process of diagnosing coronary artery disease. IVUS provides information on the composition, severity, and distribution of plaques, making it possible to estimate the coronary atherosclerotic load in a way that is not possible with other diagnostic methods. Examining the plaque conditions in the coronary arteries with the use of IVUS images with highest classification accuracy is the purpose of the current investigation. The provided IVUS image is subjected to preliminary processing in order to get rid of the speckle noise. Following the completion of the preprocessing stage, the proposed system categorizes the IVUS images into normal or abnormal. The experimental investigation indicated a high accuracy of classifying the IVUS image with more than 98% accuracy. It is not feasible by the proposed system to carry out the procedure of plaque segmentation. However, in the near future, it may be possible to construct a prototype for plaque segmentation.

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