Identification and Volume Estimation of Dental Caries using CT Image

Sabbir Ahmed[1, *], Khaled Mohammed Saifuddin[1], Abu Shakil Ahmed[2], A. B. M. Aowlad Hossain[1], and Md. Taslim Iqbal[3]

[1]Electronics and Communication Engineering, Khulna University of Engineering & Technology
Khulna-9203, Bangladesh

[2]Electrical and Electronic Engineering, Khulna University of Engineering & Technology
Khulna-9203, Bangladesh

[3]City Dental College
Dhaka-1219, Bangladesh

[*]sabbir.ahmed.delu@gmail.com

Abstract— Early detection of dental caries is vital as it causes several fatal diseases like cancer if it spreads into the root of the teeth. Therefore, early detection, tracking, and testing the depth of carious lesion may be lifesaving. In this paper, a carious detection method has been presented, and the volume of caries has been investigated. We have applied K-means clustering and threshold method for segmentation and utilized Computed Tomography (CT) images in order to construct the three-dimensional view of the carious lesion which is an integral part of the diagnosis of dental cavity. Result shows that the average Peak Signal-to-Noise Ratio (PSNR) has been obtained 19.98 and 20 by applying K-means clustering and threshold method respectively along with satisfactory visual interpretation of the three-dimensional structure of dental carries. This contribution can be applied for several other medical detection purposes with a slight adjustment.

Index Terms—**Dental caries, K-means clustering method, Threshold method, 3D construction.**

I. Introduction

Dental caries is alternatively known as tooth decay or dental cavities. Bacterial infections and deposition of acid on the enamel surface erode the hard tissues on the upper layer of teeth. This disease is so severe that even if in the developed countries over 60 to 90 percent children fall victim to dental caries due to bacterial infection where access to healthcare is comparatively easier [5]. If carious lesion spreads into the root of the teeth, it can cause cancer and several other fatal diseases. Therefore, it is better to detect dental caries as well as the depth of its spreading as early as possible. Different methods are used for detection of dental caries such as Electronics Caries Monitor (ECM), Fiber Optic Transillumination (FOTI), Digital Fiber-Optic Transillumination (DIFOTI), and Quantitative Light-induced Fluorescence (QLF) most of which are based on subjective interpolation of visual examination and tactile sensation [2-4] [7-8]. However, most of these methods have their limitations, for example, the sensitivity of FOTI and DIFOTI based methods are very low. Dentists often get confused to the results these methods produce, and they have to perceive the result with their expertise which puts patients at risk. As per ECM method, a single tooth has to be extracted in order to apply this method for the detection of dental caries which is not feasible. Moreover, the infrastructure of ECM and QLF is very expensive and hence, the cost of treatment rises [4]. QLF offers better performance than FOTI and DIFOTI as it has a high level of specificity although the sensitivity is low for this method as well. Radiography is also one of the most widely used methods to diagnose the proximal and interproximal carries though patients are exposed to radiation which is harmful to their health [6]. The Diagnodent method offers higher value for both sensitivity and specificity. Therefore, this method yields more accurate result than any of these methods. At present, computerized tomography is a well-known method for anatomic imaging of oral cavity instead of conventional imaging procedures prior to different treatments those involves surgery. Dental CT image plays a vital role in the detection of the carious lesion as we can extract various parameters from the image including the area and the depth.

In this research work, we have applied two different segmentation algorithms to determine the carious lesion affected area of an adult head part from its CT image with a view to extracting necessary information. Moreover, we have reconstructed the three-dimensional view and pixel-wise estimation of caries lesion to analyze its formation and evaluate the depth. Affected area is the region of interest (ROI) that situates inside the border of the CT image which has been identified by observing change in several properties like similarity criterion and discontinuity. The segmentation of CT images has been conducted as per the intensity of ROI.

This paper has been organized in four sections. In Section II, we have elaborated the methodology with a particular focus on the working principle of the segmentation algorithms. In section III, we have explained the simulation procedure step by step, presented the graphical results, evaluated the outcomes of the simulation works, and clarified the contribution of this paper. Section IV contains the summary of the study.

II. Methodology

The primary concentration of this research work is to investigate for a more efficient technique to detect dental caries from the CT images. In order to meet this objective, segmentation is the most critical part. Two algorithms we have applied for segmentation are K-means clustering and threshold method. Clustering is a classification technique that indicates the similarity among different regions to search the distinct groups in the feature space. It arranges data in several partitions which can be represented in n-dimensional features space. K-means clustering is a widely used method for segmentation because of its simplicity and high convergence rate, and it operates based on iteration technique [11]. This algorithm can split new classes into several regions as per similarity of the objects [9]. In fact, this algorithm compares between the index of similarity and dissimilarity for pairs of data components and divides the image into different channels. The threshold method compares every pixel in an image with a threshold value T and replaces it with a white pixel if the original pixel intensity is less than or equal to the threshold value. The threshold method has several variations such as global threshold, mean threshold, and Otsu threshold. In this paper, we have applied mean threshold method. The threshold method uses the average grey level contained within the different groups to calculate the threshold value, unlike the Otsu which is based on the discrimination criteria defined by between-class variance. In comparison with Otsu, mean threshold method offers better segmentation, and it is easier to implement [1]. An overview of the mean threshold method has been presented in Fig. 1.

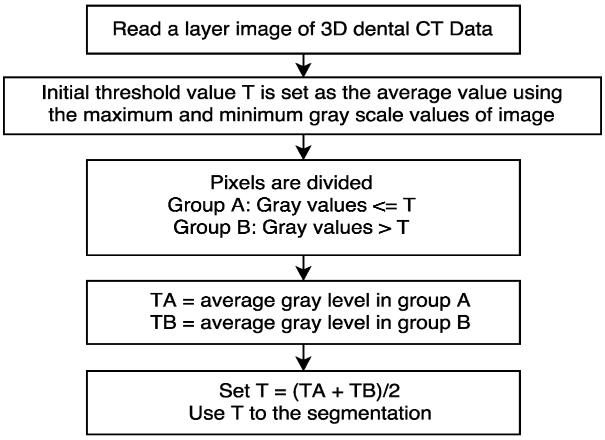

Fig. 1 Flow chart of the mean threshold method.

The feature extraction procedure separates the unnecessary portions of the image while the feature selection decreases the number of features to make classification easier. The feature extraction is the most complex procedure among the mentioned ones since the effectiveness of the classification depends upon it [10]. The workflow of the K-means clustering and the threshold method have been shown step by step graphically in Fig. 2 and Fig. 3. Moreover, we have reconstructed the three-dimensional orientation of the two-dimensional CT images constructed after feature extraction.

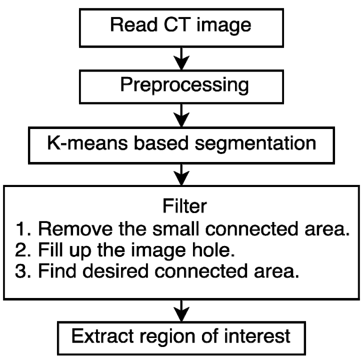

Fig. 2 Segmentation and feature extraction from CT image (2D slice) of an adult head part using K-means clustering method.

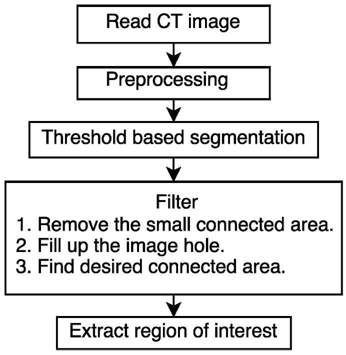

Fig. 3 Segmentation and feature extraction from CT image (2D slice) of an adult head part using threshold method.

III. Result and Discussion

A. Pre-processing

Several pre-processing tasks are required to perform prior to begin the segmentation procedure. The DICOM dental CT images have been collected from OsiriX library [12]. The two-dimensional medical CT images of dimension of 512*512 are then converted and consequent simulations are performed in MATLAB. The redundant and unwanted portion of the images has been removed in the following step. In this regard, we have cut out the redundant part of the images and put zero in the vacant places.

1) Cutting the Redundant Part: We have cropped only the region of interest from an image and discarded the rest of it as we cannot extract any necessary information from those areas. After cropping, the CT image with of dimension 512*512 has been reduced to a 234*234 matrix that forms an image shown in Fig. 4.

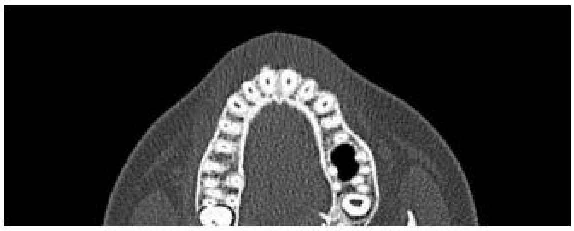

Fig. 4 Input image after removal of the redundant part.

2) Putting Zero for Vacant Space: We have placed a series of zeros in the vacant spaces after removal of the redundant parts as illustrated in Fig. 5.

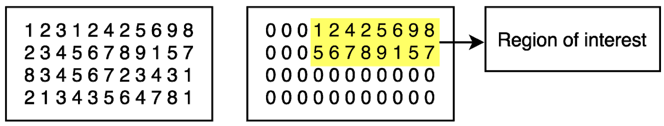

Fig. 5 Unwanted pixel elimination.

Since the image becomes less complex after elimination of the unwanted pixels as portrayed in Fig. 6, the detection process of dental caries operates faster which makes the system more efficient.

Cutting the redundant parts and putting zero for the vacant spaces both are essential for pre-processing before segmentation and they have to be performed sequentially. If we remove the unwanted regions without putting zero values, the three-dimensional representation of CT images will lose their connectivity. Therefore, we have filled the vacant regions with zeros instead of permanently removing them. Moreover, the number of necessary pixels, the operation time, and the segmentation complexity have also been reduced by this way.

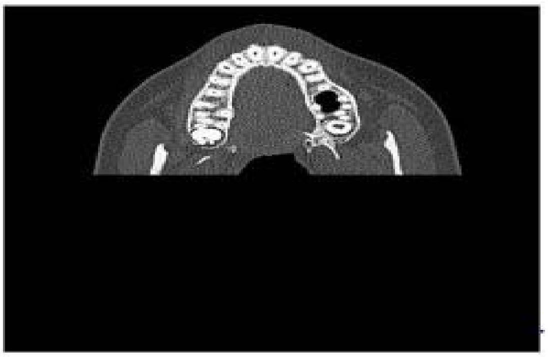

Fig. 6 CT image after putting zero to the redundant pixel.

B. Segmentation

We have applied two different algorithms for segmentation and determined the optimum one by evaluating their performances. Moreover, the working procedures of the algorithms have been illustrated step by step in this section.

1) K-means Clustering Method

We have selected spatial coordinates and L*a*b components of a pixel as the set of distinguishing features and created a five-dimensional feature vector. The K-means clustering method has been applied afterward in order to generate K clusters and hence the image is subdivided into K disjoint subsets. The segmentation algorithm assigns its pixel to its nearest centroid so that the Euclidean distance between them can be minimised into the five-dimensional features space. This algorithm completes the segmentation as intended for an arbitrary value of K. The number of segmentation varies proportionally with the value of k as the intensity level rises with the increase in K. The partition of a CT image into three channels by this algorithm has been shown in Fig. 7.

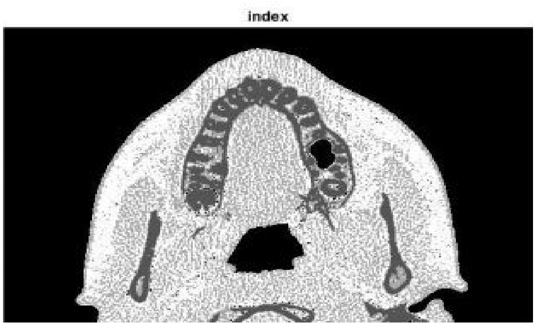

Fig. 7 CT image after segmentation using K-means clustering method.

The application of K-means clustering method has yielded each image with three different indexes, i.e., index 1, index 2, index 3 as shown in Fig. 8.

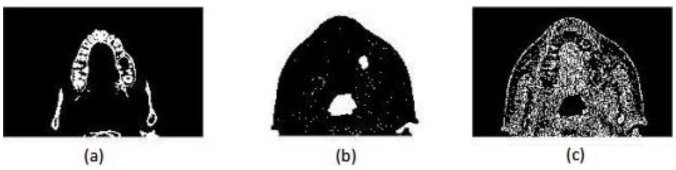

Fig. 8 Images of different index. (a) index=1 (b) index=2 (c) index=3.

Out of these three regions, one contains the region of interest. Feature extraction process can be initiated by choosing the right index, and a two-dimensional image can be formed using the extracted parametric values.

2) Threshold Method

We have used histogram shape based method in order to separate the carious lesion from other dental parts where the ISODATA is responsible for computing the global image threshold applying an iterative technique. As per the threshold method, a threshold value T has been set at first, and its value has been determined from the ISODATA. We have converted the image into binary format applying the IM2BW technique. The histogram has been segmented into several parts by comparing with the threshold value. Moreover, the sample mean of the grey value associated with both the foreground and the background pixels has been calculated. The grey value has been set 0 if it is beyond the preset threshold value and 1 otherwise. The threshold value has been updated after conducting these steps, and the process has been continued until the further change in threshold value. By this way, the CT images have been segmented. Fig. 9 represents the scenario of dental CT image after pre-processing and segmentation using threshold method.

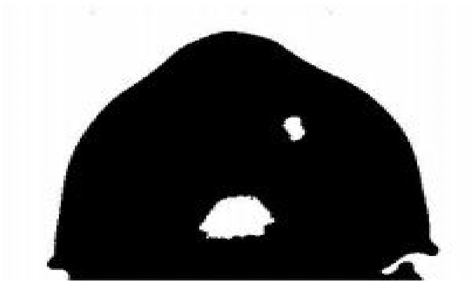

Fig. 9 Dental CT Image after segmentation using threshold method.

C. Extraction

We have extracted the region of interest from the segments of CT images by applying feature extraction method with a view to conducting further analysis. The chosen parameters are the pixel intensity of each pixel and the number of connected pixels which are selected for the quantitative reflection of similarity and discontinuity.

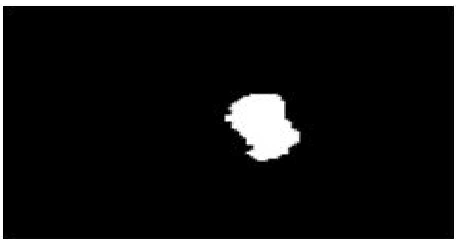

Fig. 10 The extracted region of interest for K-means clustering method.

A separate matrix has been formed containing the parametric values, and an image has been generated that incorporates all the connected components. In this manner, the region of interest has been extracted as a two-dimensional image that facilitates further analysis on the area, depth, and several other properties. Fig. 10 and Fig. 11 shows the extracted region of interest for K-means clustering method and threshold method respectively. Here, a sharp segmented region has been obtained for threshold method.

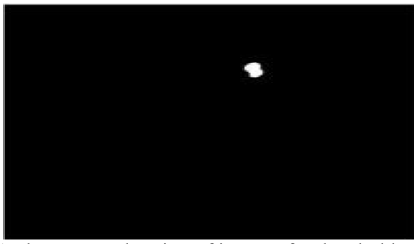

Fig. 11 The extracted region of interest for threshold method.

D. 3D Construction of Cavity

After conducting pre-processing, segmentation, and extraction process, we have constructed a three-dimensional image of the dental cavity. The dimension consists of X, Y, and Z-axis where the two-dimensional images generated by extraction process have been placed along the XY plane, and the Z-axis maintains the serial number of images. The serial number or image sequence as per the three-dimensional matrix is vital to retain the connectivity among the images. We have used a 3D viewer software to observe the three-dimensional images of the dental cavity presented in Fig. 12.

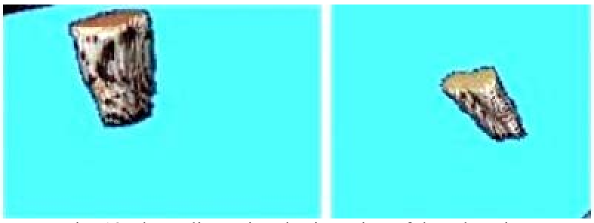

Fig. 12 Three-dimensional orientation of dental cavity.

We have evaluated the performance of the detection method illustrated earlier and clarified the contribution of this study. While conducting the simulation, we have measured the value of several parameters in order to track the progress of the dental cavity along with its detection. We have measured the PSNR = $10\log_{10}$(peak value/MSE) of the segmented images for both the K-means clustering and the threshold method corresponding to the original CT images. The recorded PSNR values of the segmented images have been presented in TABLE I. It can be observed that the two segmentation methods negligibly differ from each other regarding the PSNR value. Therefore, it is evident that the same PSNR has been maintained throughout the simulation. However, the threshold method is more convenient for segmentation as a sharper segmented region has been obtained for this method in comparison with the K-means clustering.

TABLE I PSNR OF THE SEGMENTED IMAGES

Main Image	PSNR (K-means clustering)	PSNR (Threshold method)
IM-0001-0050.dcm	20.01	20.04
IM-0001-0051.dcm	20.05	20.07
IM-0001-0052.dcm	19.92	19.92
IM-0001-0053.dcm	20.01	20.00
IM-0001-0054.dcm	19.91	19.91
IM-0001-0055.dcm	20.02	20.06

We have measured the number of pixels in each segment of the images during the simulation process as the number of affected pixels can be determined by comparing with the number of pixels of the original CT image. By this way, we have identified the areas affected by dental caries. Moreover, using the pixel information we have determined the volume of the carious lesion. TABLE II represents the number of actual pixels in each segmented volume.

TABLE II NUMBER OF ESTEMATED PIXEL IN EACH SEGMENTED IMAGE

Main image	No. of estimated pixel in segmented volume (K-means clustering)	No. of estimated pixel in segmented volume (Threshold algorithm)
IM-0001-0050.dcm	140339	150167
IM-0001-0050.dcm	116847	120764
IM-0001-0050.dcm	101862	102582
IM-0001-0050.dcm	79163	790821
IM-0001-0050.dcm	58852	58359
IM-0001-0050.dcm	33426	38669

IV. CONCLUSION

The key concentration of this paper is to identify dental caries as well as examining the depth of the carious lesion. In this regard, we have prepared the medical CT images for simulation through some pre-processing works. The segmentation of the images has been performed using K-means clustering method and threshold method separately in order to compare the performances of these two algorithms. The necessary features have been extracted from the segmented images to form a two-dimensional matrix at first and later a three-dimensional matrix in order to construct a three-dimensional orientation of the dental cavity. During conducting the simulation, we have recorded the values of PSNR and calculated the number of effective pixels with a view to detecting dental caries and estimating its volume. The effectiveness of this study has been justified by both graphical and numerical measures.

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