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Research Article

Early Carious Lesion Detection and Feature Extraction Based on Colour Image Analysis

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Abstract

Dental caries is a painful, bacterial disease of teeth caused by acid, carbohydrates. This decayed the enamel, dentine layer of the teeth. Almost 8 billion people suffer from dental caries around the world. Among them, 50 - 60% is children and they often don't get adequate treatment. Periodic monitoring and treatment is essential to preventing the growth of the caries starting from school level. It is difficult for doctor to keep track the progress of affected lesion. That case, x-ray is helpful although it is injurious to health. Hence optical image based caries monitoring system is advantageous to monitor the size of the lesion. It is safe for the children and pregnant ladies. In this paper we propose a new, safe and low cost early caries detection method based on optical images of teeth. This system segments tooth, carious lesion and monitor the affected lesion size. The main goal of this research work is to find the exact affected carious lesion and it's features that assist dentist for better follow-up and diagnosis.

Keywords: Carious Lesion; Dental Caries; X-Ray

Introduction

Dental caries is one of the most common oral diseases. It is caused by the action of acids on the enamel surface [1]. Existing diagnostic techniques for caries detection include visual examination, radiography, and fiber-optic trans-illumination. Most of the caries detection methods are primarily based on visual examination and tactile sensation. These methods can detect the caries region in any stage other than the early stage.

Although there are known drawbacks like, visual inspection has been claimed to be the best diagnostic method in populations with low caries prevalence, but it is unable to correctly detect caries lesions because of its low sensitivity [2,3]. The main shortcomings of the conventional methods are that, it is difficult to evaluate a lesions progress rate. Radiography is the most common method to diagnose proximal caries and it also exposes the patient to a relatively high dose of ionizing radiation. Frequently taken x- ray changes our DNA structure that leads to cancer [4]. X - ray images of teeth provide very less information, whereas dental CT image provides much information that helps for better treatment. However cone bean computer tomography is very expensive. In short we can say that although the existing methods like quantitative light induced fluorescence (QLF), Diagnodent, Foti, DiFoti [5,6] etc methods offer relatively good diagnostic performances but they provide varying sensitivities for detecting same carious lesions. However segmentation and manipulation of teeth image, separation of the upper and lower jaws is very much challenging.

In that case dental x-ray images are advantageous [7]. Another important thing is that X-Ray is not suitable to detect enamel caries due to the coronal morphology of subsequent teeth. X-ray images could not be used for monitoring purpose, because it is harmful to our health. However X -Ray can measure the depth the caries. To overcome these kinds of problems we proposed a method based on RGB tooth segmentation. This method is able to find out teeth wise exact carious lesion size. At the early stage of caries, the enamel color is being started to changed, this method also capable to identify whether a teeth is affected in caries. Proposed method also finds, the teeth wise carious lesions features like, volume, height, width, aspect ratio etc.

In this method the teeth images are gone through the Guided filter [8] to make it noise free. Color based segmentation technique is used to find the only tooth region from reflected gum, lips and tongue region. After that tooth are segmented from the whole tooth region based on the concept of changing of the tangent of the boundary curve and various morphological operations. Finally the caries affected areas have been pointed out depending on the hue value of the teeth. The aim of the research work is not to automate the caries detection dentistry system nevertheless to co-operate with dentist to detect caries with enormous accuracy. Based on the previous discussion of different types of existing segmentation techniques, we conclude that the task of low -cost, automated teeth caries detection is indeed challenging. This work aims to strike a balance between the cost and quality perspectives. Though X-Ray images are inexpensive but it contains huge noises, sometimes to remove these noises a number of important imaging information are lost. Hence we propose a new method based on Red, Green and Blue component of the input teeth image to overcome this problem.

There are some existing methods [9,10] based on photographic color images with the red (R), Green (G) and Blue (B) components to detect caries area. However, the method fails when flash light is reflected and also for non-uniform background. Our proposed method is resilient to such failures and detect caries lesion with more than 93% accuracy.

Complete System Design

The entire work is divided as ‘Preprocessing Block’, ‘Segmentation Block’ and ‘Output Block’ which is shown in figure 1. Image acquisition and filtering are done in pre-processing block. Segmentation block is divided into two parts; in initial segmentation phase, the only teeth region is segmented from gum, lip and tongue regions and the tooth segmentation phase segment the individual tooth from the teeth.

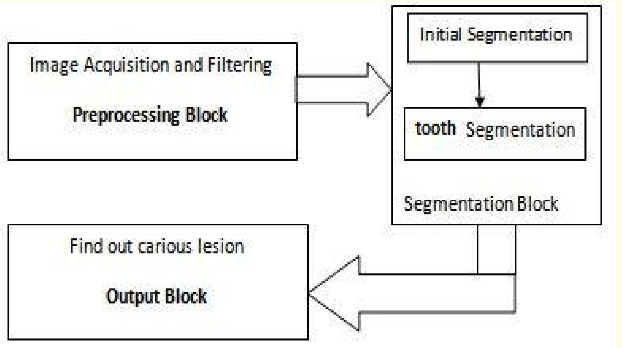

Figure 1: Block Diagram of the proposed method 3.1 Image Enhancement/Sharpening.

The aim of image enhancement is to improve the interpretability of information in images and improvement of digital image quality for further processing techniques. The qualities of the images that are obtained from the intraoral camera are not so good. Here Guided Filter [8,11] is used to remove the noise. Guided filter is used for edge-preserving smoothing purpose. Guided filter effectively suppress the gradient artifacts and produce visually good quality image. Suppose I, p, q represents guidance image, input image and output image respectively. Then the guided filter would follow a linear model like,

q_i	$a_k I_i$	b_k	$i\ w_k$	(1)

Where i is the index of a pixel, and k is the index of a local square window ω with a radius r. The algorithmic steps are given as below. Here f_{mean} (.,r) denotes the mean filter with a radius r.

Step 1: Calculate the mean of guided filter, $mean_I\ f_{mean}\ (I, r)$

Calculate the mean of input image, $mean_p\ f_{mean}\ (p, r)$

$corrI\ f_{mean}\ (I.*I, r)$

$corrIp\ f_{mean}\ (I.*p, r)$

$Var_i\quad corr_i\ \ mean_I.*mean_I$

$Cov_{IP}\quad corr_{IP}\ \ mean_I.*mean_p$

Step 2: a cov_{IP} . /(var_I C)

Step 3: $^{bmean}p\ ^{a.*\ mean}i\ mean_a\ f_{mean}$ (a, r)

Step 4: $^{mean}b f_{mean}\ ^{(b,\ r)}$

q $mean_a$.* I $mean_b$

Step 5: End

Guided filter also removes the blurriness of the image. The output images are taken for further analysis.

Information Extraction

It is not possible to extract only tooth region from a gray image because some gum region looks like white due to light reflection. Therefore using the threshold based segmentation can’t isolate the teeth and non-teeth region properly. Teeth region is whitish whereas gum, tongue all is reddish. Hence color based segmentation can’t properly extract the teeth and non-teeth region. HSI color model [12] has been used to identify the color variation like light pink, dark pink etc. Here, H stands for Hue i.e. pure color, S for saturation i.e. the degree by which the pure color is diluted using white light and I for intensity i.e. gray level.

Initial Segmentation

Partially supervised segmentation technique [13,14] is used to separate the teeth and non-teeth region. In this method cluster centers are pink for lip region, white for tooth region and reddish for gum and tongue region. Hue component of a tooth has been separated from the whole image.

Final Segmentation

In the binary image black i.e. non- teeth region and white i.e. teeth region is present. Both of these regions contain some white spots and black spots respectively. These are called noise. Noise can be removed separately from white region and black region using erosion [15]. By applying this erosion technique the white spots in the black region are removed. Now negate the image to remove the noise and applying the same erosion technique from the tooth region.

Segmentation of individual teeth

Next step is to segment each tooth from a set of teeth. To do so the notch points have to be isolated. These notch points are detected by observing the changes of the tangent of the boundary curve. Procedure named “Individual_Teeth _Segmentation” is used to segment each tooth. The binary image where non-teeth contours are removed is used as an input image to the system.

Procedure: Individual_Teeth _Segmentation

Assumptions: Nil

Input: The output of Cluster_Based_Segmentation algorithm

Output: Segmentation of individual teeth

Step 1: Apply label matrix technique, where each contour pixel is marked with a different integer number to find the largest contour that contains the maximum number of pixels.

Step 2: Find the boundary points of the largest contour.

For I = 1 to end_column

Y_data_L [i] = find the lowest row number in the ith column where value=1

Y_data_H[i] = find the h row number in the ith column where value=1

End for loop

Step 3: Re-sampling the data (Y_data_L) to reduce the computation time by applying Nyquist formula and store the new sample into y_data_L_New vector.

Step 4: Find the points from Y_ data_L_New where value varies widely from positive to negative value or consecutive value has huge difference.

Step 5: The value obtained from step 4 is the notch points from where segmentation should start. Store the position in L Matrix that contains two rows: one for row index and another for column index. Now, subtract Y_data_H values from row number and store the result in Y_data_H_New. Repeat step 3 and step 4 upon Y_data_H_New and store the result in H Matrix.

Step 6: for i=1 to total_no_of_element_L

Calculate the Euclidian distances between ith point in L matrix and all points of H Matrix. Find the lowest value and corresponding point.

Step 7: Input the two end points and store the left end point in (x0, y0)

Calculate the constants Δx, Δy, 2Δy and 2Δy-2Δx and decision parameter d0 = 2Δy- Δx

At each xk along the line, starting at k=0, perform the following test:

If dk < 0,

the next point is (xk+1 , yk) and dk+1 = dk + 2Δy

Else

Point to plot is (xk+1, yk+1) and calculate dk+1 = dk + 2Δy - 2Δx
Repeat above step Δx times

End for loop

Step 8: Stop.

Procedure: Caries_Detection

Assumption: Nil

Input: Modified Image where tooth region is extracted from non-teeth region.

Output: Segment the affected area (caries region) from the input image

Step 1: Extract the tooth contour from the mask, shown in figure.

Step 2: Dilate the mask and store the result in thick_mask, shown in figure (next).

Step 3: Boundary _Points = [thick_mask – (thick_mask U mask)],

Step 4: Find the average hue value of the points belongs in Boundary_Points and store it in Avg_Hue variable. And fill the non-teeth region with that value.

Step 5: Apply partial supervise Clustering technique discussed in "Cluster_Based_Segmentation" algorithm to segment the caries region.

Step 6: Extract each clusters coordinates and compare them with each tooth to point out the exact carious lesion.

Step 7: Stop.

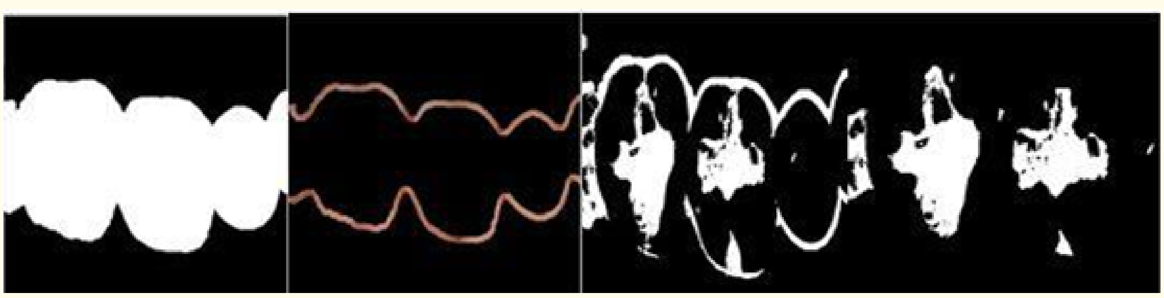

Figure 2: Thick Mask, Boundary Points, Caries with Boundary Region and Only Carious Lesion.

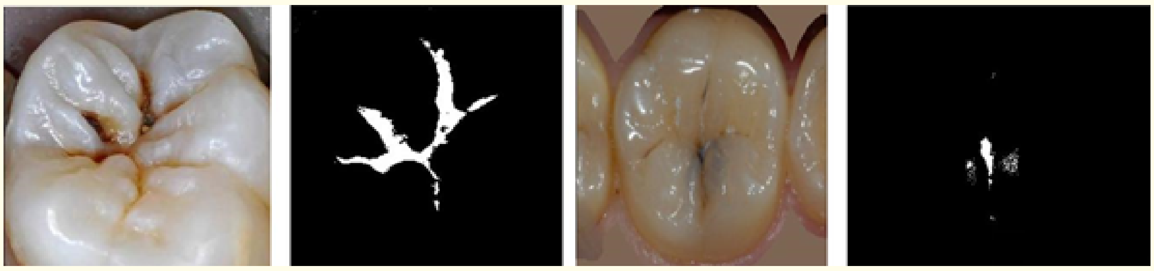

Figure 3: Caries affected lesion for set 2 and set 3 input.

Simulation and Result

The entire work is divided into two subsections, the first one is region segmentation of each individual tooth among a set of teeth. And the second one is detection of caries area and trying to estimate the size of affected area. Our method has been tested on Labial Teeth and Gingival Image database [16]. The proposed system is compared with two other method named, "Detection of occlusal caries based on digital image processing" [8] and "Quantitative light-induced fluorescence QLF". In the first method tooth are firstly extracted firstly after that exact caries region are segmented from a green background and in this method there is no reflection of light and saliva because the teeth are dried properly. This method fails to detect caries region where reflection of light is present and teeth are not dried properly. But our proposed method has been able to detect exact caries region under this circumstances. In case of QLF machine, it has recently launched in the market. This new method uses the principle of fluorescence for caries detection. It is very costly machine and not fully automated. But this method provides good result not only detecting the affected area but also monitoring the caries lesion. Table 1 shows a comparative study between these methods regarding the caries detection.

Matrices	Detection of occlusal caries based on digital image processing	Quantitative light-induced fluorescence QLF	Our method	Remarks
Sensitivity	43.80%	68%	85.63%	The 1st method able to detect caries from green background and fails to detect caries in case of saliva
Specificity	53.21%	77%	70.74%	QLF software is equipped with several tools to manage very large databases of multiple patients so it is very complicated.
Error Rate (w.r.t. tooth Region Segmentation)	22.73%	**	6.60%	** QLF method uses staining material. Hence error rate depends on the staining quality.
Accuracy	77.27%	94.45%	93.48%	Proposed method gives better result to detect caries in molar and premolar teeth.

Table 1: Performance Analysis of different methods.

Carious lesion is identified now; then our task is to find out the features of the subject wise carious lesion. Here we consider 5 features of the carious lesion like height of the lesion, width of the lesion, aspect ratio of the lesion, major axis length, minor axis length, convex area and smoothness of the lesion. Figure 4 represents the geometric definitions of the features. Table 2 shows the features.

Subject Number	Height (mm)	Width (mm)	Aspect Ratio	Convex Area	Smoothness
S_1.	2.2	1.5	1.46	3.94	.5625
S_2.	1.9	2	0.95	3.01	.3451
S_3.	2.6	2.1	1.23	3.89	.6721
S_4.	.98	1.78	.5505	2.89	.1209
S_5.	3.89	2.45	1.58	4.52	.0452

Table 2: Different Features of Carious Lesions.

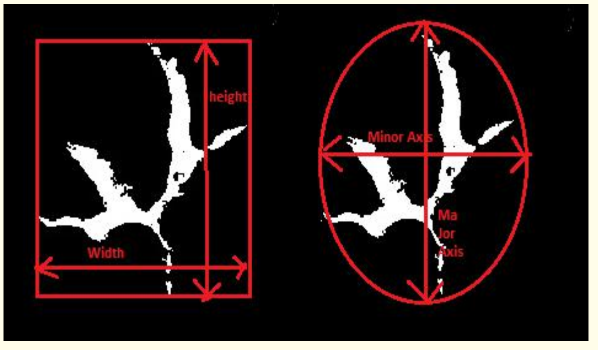

Figure 4: The feature definition of carious lesion.

Result Analysis

Our proposed method offers almost 93.5% accuracy, error rate is also comparatively very less than method 1. Average performance time is 2.5 - 3 seconds and every intermediate image like mask, segmented teeth, caries mask are stored, and hence storage requirement is higher than the other method.

On the other hand, no information has lost in this system. Sensitivity has been calculated as $\frac{TP}{TP+FN}$ where TP is True Positive and FN is false negative. In our sample images gum region, tongue region is present hence to detect this unwanted points from the entire teeth region the value of FN is increased. In this method saturation matrix is used to segment non-teeth region so color chrominance variation can be overcome. Image opening and closing techniques are used to remove unnecessary contours. Due to these reason the sensitivity of our proposed method is much higher than the other method.

Conclusion

The proposed caries detection technique is comparatively less expensive w.r.t., other methods. It uses visible light. Hence it is not harmful for human being. QLF uses staining material which has side effect. Our proposed method can detect caries lesion with more than 93% accuracy. However, it fails to detect individual teeth in case of a broken tooth. The proposed method works only on the surface of the tooth enamel and it is unable to detect the depth of the caries. In such cases, X -Ray images might be helpful. The current work may further be extended to build a holistic solution using RGB and other types of images to detect the shape and depth of the caries lesion respectively.

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Volume 1 Issue 6 November 2017