Detecting Smooth Surface Dental Caries in Frontal Teeth Using Image Processing

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ABSTRACT
Dental caries is one of the most common tooth diseases in the world which affects people of all ages. In this study, we developed a model that detects and locates smooth surface carious regions in frontal teeth images using Support Vector Machine and Decision Tree in MATLAB R2018a Classification Learner. A total of 45 images with smooth surface dental caries were used which consists of 30 training images and 15 images for testing and validation. Images are pre-processed using Histogram Equalization and are segmented further into 10x10 blocks where the set of color and texture features such as Intensity, Gradient, Hue, Saturation, and Entropy were extracted. The study showed significant results with an accuracy of 84% and 78% using Decision Tree and SVM respectively which proved the effectivity of the use of image processing techniques on classification and location of dental caries.

CCS Concepts
Applied computing → Life and medical sciences → Consumer health

Keywords
Smooth surface dental caries; svm; decision tree; image processing.

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1. INTRODUCTION
Dental caries are infections in human teeth caused by numerous types of bacteria inside the mouth [1]. The occurrence of white chalk like mark on the tooth surface is an early sign of dental caries which can indicate demineralization of the enamel, dental caries lesion can also be characterized by having a shiny dark brown spot in the tooth surface [2, 3]. A healthy tooth without dental caries is free from discoloration and destruction of enamel and dentin. Dental caries can further damage the teeth which may result in tooth cavities or holes inside the tooth [1]. Traditionally, visual probing techniques are used by dentists for the diagnosis of the dental conditions of the patient [4]. The two most commonly used clinical techniques to diagnose dental caries are by the mirror and test examination, or by utilizing radiography [5]. Visual observation of the discoloration and texture of the teeth are factors the clinician heavily relies on diagnosing dental caries. The approach for detecting dental caries, diagnosis, and management of carious lesions vary due to the difference of assessments between different clinicians [4].

This research focuses on detecting Smooth Surface Dental Caries and locating caries regions from frontal teeth images captured using an 8-megapixel smartphone camera [6] with an aperture f/2.2 together with LED flash which is used to capture the photographic images of the frontal teeth. The images were captured under room light conditions and the age of participants ranges between 15 and 25 years old with natural teeth, without dentures, and other orthodontics. Using MATLAB, the acquired images were pre-processed by contrast enhancement using Histogram Equalization. Images were then segmented into 10x10-pixel blocks using Block Segmentation, these image blocks were classified to determine whether it is carious or non-carious by using SVM and Decision Tree while applying the extracted features from the images which consists of only the color and texture features: Intensity, Gradient, Hue, Saturation and Entropy acquired by utilizing MATLAB. After individual pixel regions are classified, regions were highlighted to show the regions affected

by dental caries. The aim of this research is to detect the occurrence of caries in the teeth based on the color and texture features using SVM and Decision Tree, and to highlight the locations of the dental caries regions.

2. RELATED LITERATURE

Koutsouri et al. Developed a system that detects occlusal caries using photographic color images. The digital colored images consisting of 91 posterior teeth and 12 in vivo ¬ human teeth were pre-processed and converted to grayscale by the elimination of the saturation and hue while the luminance of the image was retained, and the contrast of the image was enhanced. In the segmentation step, objects that do not correspond to the areas of interest were eliminated by applying the k-means algorithm. They utilized five different unsupervised classifiers to detect dental caries consisting of J48, Random Tree, Random Forests, SVM and Naïve Bayes with the feature set consisting of texture based and intensity-based features. The study has two stages, first is the Detection stage, which detects the affected regions followed by the Classification stage, which classifies dental caries according to its corresponding ICDAS classification. The study achieved an accuracy of 83% [4].

In a study conducted by Datta et al, they developed a system that detects dental caries lesion based on image analysis techniques. The images are acquired using an intra-oral camera. In the preprocessing step, they removed the noise of the images by applying the Wiener filter and segmented the image to individual set of teeth using Cluster-Based Segmentation. Using MATLAB, they processed the features extracted and segmented regions containing dental caries. Their proposed model can detect carious lesion with more than 93% of accuracy however it is unable to detect the shape and depth of the caries lesion [7].

This section is an outline of techniques used by previous studies for detecting dental caries. In the table shown below, 8 studies on detecting dental caries using image processing are surveyed with the criteria which include the Dataset, Preprocessing, Segmentation, Feature Extraction, Classifier, and the Results.

Table 1 shows the evaluation of the techniques used in each phase to detect dental caries. Datasets from previous studies vary from radiographic images, intra-oral, panoramic, optical and digital images. For the detection of dental caries, several steps are required which varies among different studies.

Table 1. Evaluation on studies on detecting dental caries

Ref	Title	Dataset	Pre-processing	Segmentation	Feature Extraction	Classifier	Results
[9]	Detection of occlusal caries based on digital image processing	60 digital color tooth images	Contrast Enhancement	k-means	Texture and shape of the area	Five non - supervised classifiers (Unspecified)	Sensitivity is 92% and the precision is 80%.
[2]	Caries Detection Technique for Radiographic and Intra Oral Camera Images	Not specified	Image conversion to BW	Thresholding	Model-Based	Not Specified	Very efficient and precise.
[1]	Diagnosis of Dental Cavities using Image Processing	120 digital periapical X-ray radiograph images	RGB to Gray Conversion Binary Conversion	Region-Based	Not Specified	Not Specified	Not Specified
[7]	Detection of Dental Caries Lesion at Early Stage Based on Image Analysis Technique	45 images	Remove noise using Wiener filter Color space conversation of RGB to HIS	Cluster-Based Segmentation	Tooth Contour Average Hue	Not specified	Accuracy greater than 93%
[5]	A New Optimized Approach for Detection of Caries in Panoramic Images	100 panoramic images	Conversion of sounds from analog signals into digital signals	Thresholding	Histogram of Oriented Gradient (HOG)	Support Vector Machine	Training 97.2% Validation 86.7% Testing 92.4% Overall 92.1%
[8], [9]	An automated dental caries detection and scoring system for optical images of tooth occlusal surface	19 premolar teeth images 69 molar tooth images	Histogram-based contrast enhancement	Region growing method Circular Hough Transform Morphology Operation	Mean of matrix elements Entropy Gradient	Random Forest	86.3% of accuracy 98.3% of Specificity 83.0% of sensitivity
[10]	Classification of Dental Diseases Using CNN and Transfer Learning	251 x-ray images	Not Specified	Not Specified	Applied Pre-trained VGG16	Convolutional Neural Network	88.46% accuracy achieved

[4]	A computer-aided automated methodology for the detection and classification of occlusal caries from photographic color images	91 Posterior teeth 12 in Vivo human teeth	RGB to Gray Convert to binary Contrast Enhancement Flood Fill Algorithm Perimeter Extraction Depiction of Center	K-means algorithm	Texture-Based: Co-occurrence Matrices Local Binary Patterns Intensity-Based: Mean Intensity Entropy	J48 Random Forests Support Vector Machines Na ïve Bayes	83% accuracy

A Preprocessing step has been utilized by numerous studies in order to improve the quality of the images acquired. [8] used Histogram based Contrast Enhancement to improve the performance of the subsequent image processing steps. Other studies used different techniques on enhancing the image such as Binary Conversion [1], Image conversion to BW [2], etc.

Different techniques on image segmentation are applied in the previous studies prior to the feature extraction step such as Segmentation by K-means [9], Region-based [1], Cluster-based [7]. [8] used a 10 x 10 window to extract and calculate features from the tooth regions and surfaces.

There are multiple features to extract from an image according to the previous studies. In the study [4], they used contrast, homogeneity, energy, and correlation which are texture-based features, mean and entropy which are intensity-based features and local binary patterns. These features are extracted from a 15x15 pixel block from the regions of interest. A set of 132 features are created per pixel since the features are extracted from different color channels. In other studies, model-based [2], tooth contour and average hue [7], histogram of oriented gradient [5] were used as the features to extract from the images.

In [5], a Support Vector Machine is utilized as a classifier which acquired a 92.1% overall accuracy. SVM has evolved for solving problems on regression and classification depending on the applied mathematical learnings. This classifier obtained satisfactory results from different studies. Other studies have utilized algorithms such as Random Forest [8] and Convolutional Neural Networks [10] and have achieved significant results in detecting dental caries.

Previous studies can be further improved by using a different type of image particularly by detecting smooth surface caries found in frontal teeth images as well as highlighting the location of the caries lesion.

3. PROPOSED METHOD

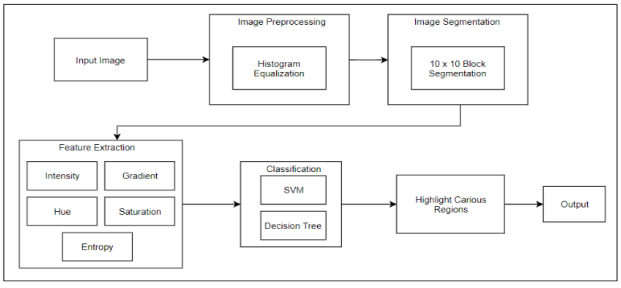

Figure 1. Proposed model for dental caries detection and location.

Our proposed dental caries detection model contains four steps which are: *Image Segmentation*, *Feature Extraction*, *Classification*, and *Location*. Figure 1 shows the proposed model for dental caries detection and location.

3.1 Image Preprocessing

The quality of the images acquired using a smartphone camera may not be at its optimal form. The researchers applied histogram equalization which is a technique utilized to enhance the image appearance and quality. Histogram equalization utilizes a non-linear and monotonic process that orders the histogram for the different values of intensity in each pixel [11]. Figure 2 and Figure 3 shows a comparison between the original image and the pre-processed image. The caries regions in the pre-processed image can be easier to visually spot due to the enhanced contrast.

Figure 2. Original image.

Figure 3. Pre-processed image using histogram equalization.

3.2 Image Segmentation

Image segmentation can be used in order to increase the efficiency of the classification algorithm. The pre-processed images from the previous step were block segmented into 10 x 10 blocks. The resulting segmented blocks of images were then used for the feature extraction phase.

3.3 Feature Extraction

A total of five features of the image were used for feature extraction. The *Intensity* of the image represents the total brightness of a pixel. The higher the intensity of the image, the

whiter the pixel will appear. The magnitude of the *Gradient* of the image will be extracted in order to determine the rate of change in relation to the color of the image. This can indicate a significant shift of color in the image. The *hue* represents the color of the image which can be used to isolate between the teeth and non-teeth regions. *Saturation* is the extent to which a color is diluted using white light and *Entropy*, which is a statistic feature of texture that pertains to the measure of irregularity of the intensity of an image.

3.4 Classification

For classification, the researchers used Support Vector Machine and Decision Tree. Features extracted from the pixel blocks from the previous step were supplied to the SVM and Decision tree classifier and classifies whether the certain pixel block has dental caries or is healthy. At the end of the classification step, a map containing the regions of the image diagnosed with dental caries was created.

3.5 Locating Carious Regions

The mapping which contains the location between the carious and non-carious regions from the previous step was used to highlight regions in the image deemed by the classifier as carious. From the original input image, the regions will be highlighted in order to show the regions with dental caries.

4. RESULTS AND DISCUSSION

In this study, the researchers used MATLAB R2018a to develop and test the model. The proposed methodology utilized 45 digital color images. These images are further subdivided into two; the training data set, and the testing data set applying the 70-30 distribution. The training data set consists of 30 images and the remaining 15 images were used for testing the model.

The images were pre-processed by applying histogram equalization to enhance the contrast of the input images. After the images are pre-processed, each image was segmented into 10x10 pixel blocks where the mean intensity, gradient, hue, saturation, and entropy was acquired.

From the 30 digital images from the training data set, 100 regions of interest were extracted from the original images, 60 of these are regions that contain dental caries (class 1) and 40 are regions that are healthy (class 0). The regions of interest extracted were segmented into 10x10 pixel blocks wherein each block, the intensity, gradient, hue, saturation, and entropy were extracted. Using the MATLAB Classification Learner Tool, a total of 7654 feature vectors were used to train the classifiers Decision Tree and SVM where 10-Fold validation is used, the results of the training are displayed in Table 2.

Table 2. Training results

Classifier	Accuracy	Precision	Recall	F1-Score
SVM	81.79%	78.99%	81.58%	0.80
Decision Tree	97.14%	97.10%	96.80%	0.97

From the input images, regions are labeled using the trained classification algorithms, the input image is segmented into 10x10 pixel regions where each 10x10 region will then be classified whether it contains dental caries (class 1) or is healthy (class 0). The testing data set contains 15 images that are used to test the trained model. The trained model can easily classify regions containing dental carries with dark or yellowish discoloration but can misclassify regions with calcification as healthy. The model can sometimes produce false classifications due to the tendency of smartphone cameras to improperly focus on images within a short distance, lighting inconsistencies, as well as on how the image was captured. The 10x10 pixel regions that are labeled as carious by the classification algorithm are highlighted by setting the R values of the RGB images to zero which produced the blue-green highlight effect. In Figure 4, caries regions are marked by an expert and all regions marked are diagnosed with dental caries including early signs of dental caries. Figure 5 and 6 shows the comparison of results between SVM and Decision Tree.

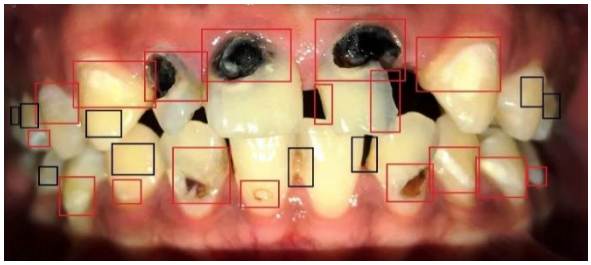

Figure 4. Input image (Regions Highlighted).

Figure 5. Output image using decision tree.

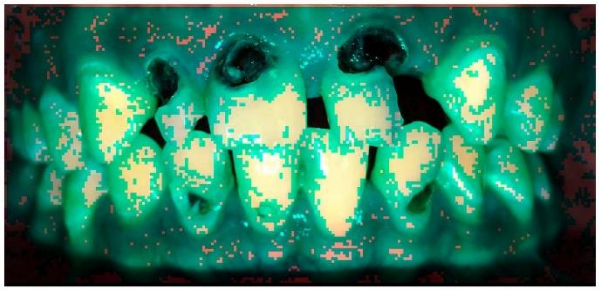

Figure 6. Output image using SVM.

The decision tree algorithm was able to correctly locate carious regions and regions with yellow discoloration with an accuracy of 84% whereas SVM produced an accuracy of only 78%. Table III shows the result of the classification and location stage.

Table 3. Classification and location results

Classifier	Accuracy
SVM	78%
Decision Tree	84%

5. CONCLUSION

We presented a method for diagnosing smooth surface dental caries from photographic images captured using smartphones. The use of smartphones as compared to other instruments for acquiring dental images such as intra-oral cameras or x-ray is relatively cheaper and faster.

In this study, 45 images are subdivided into training (30 images) and testing datasets (15). 100 regions of interest were extracted from the training data set which produced a total of 7654 feature vectors was used to train the model. To improve the overall image quality, Histogram Equalization was used in the pre-processing set where the contrast between healthy regions and caries regions were enhanced. The following features: Intensity, Gradient, Hue, Saturation, and Entropy were used as the set of features for the machine learning algorithms SVM and Decision Tree. During the training phase, SVM and Decision Tree were able to successfully classify between carious and healthy pixel regions with an accuracy of 82% and 97% respectively applying 10-fold validation. The algorithm can identify and locate the affected regions but can produce several false classifications. The results showed that Decision Tree-based algorithm outperforms Support Vector Machine when classifying pixel regions. The set of features selected produced an outstanding result that provided a relatively high accuracy and precision for the classification algorithms and can successfully detect carious and non-carious regions with a relatively small error rate. The accuracy and precision of diagnosis greatly depend on the quality of the camera used, lighting conditions, as well as on how the image was captured. The classification and location accuracy can be further increased by utilizing more images under different light conditions and camera to train the model.

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