Analysis of Tooth Caries using the Deep-learning Model with Fused Features: A Study

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Abstract. In humans, the disease occurrence is happens in several ways and to manage it, it is necessary to implement appropriate diagnosis and treatment. Maintaining the oral health is a prime task and any abnormality will lead to various other health issues. This work considered the tooth enamel caries for the examination, which needs early diagnosis and treatment. This research proposed deep-learning scheme with EfficientNet (EN) model based examination of the tooth enamel caries. When a digital photograph of the tooth region is available, it is easy for evaluation the severity. This research presented a work to identify he mild and harsh enamel caries from the tooth based on the digital images. The different phases of this work includes the following sections; tooth-image collection and modifying its dimension, deep-features extraction with En-model, Softmax-based classification and identification of best two DL-model, reducing its features to 50% and serially integrating these values to generate a fused-feature vector, and verifying the merit using the machine-learning classifiers and 3-fold cross validation. The result of this work confirms that the developed system works well on the image database and provides>98% with the considered image examination task.

1 Introduction

Oral health is a vital component that must be present in every individual in order to bring about total wellbeing. If you have any dental problems, it will have a significant impact on your quality of life. No matter a person's age or gender, tooth enamel caries (TC) is a ubiquitous dental problem that affects people all over the world. Bacterial activity, demineralization, and plaque accumulation are the three factors that contribute to the progression of this condition, which ultimately leads to tooth caries. If the TC is ignored, it will result in extreme discomfort, infection, and eventually the loss of teeth. As a result, the quick detection and action of oral problems are absolutely necessary in order to alleviate them. Self-evaluations and clinical examinations carried out by a dentist are the two approaches that are considered to be standard options for evaluating oral health. The initial evaluation is carried out by the dentist by either an eye inspection or a digitally assisted photographic examination. In this examination, the damaged tooth is evaluated through the utilization of a digital camera and several computer algorithms. The initial analysis can be accomplished through the use of this conventional method, while the lateral analysis can be carried out through the utilization of dental radiography [1,2].

As a result of the difficulty of the traditional method of evaluating oral health, modern techniques have made use of computer algorithms to assess dental photographs. The pictures will be classified into severe and mild caries based on the results of this study, and the appropriate treatment procedure will subsequently be utilized to correct the condition. Deep-learning (DL) algorithms are utilized in modern procedures in order to locate cavities through the utilization of computer-aided techniques. This is done in order to overcome the constraints that are associated with conventional procedures. In the course of performing fundamental image analysis tasks, such as segmentation and classification, the DL-scheme that was built has demonstrated improved accuracy. In addition to this, it assists in the enhancement of clinically important outcomes based on the imaging modalities that are taken into consideration. This research made use of a deep learning model that implemented a transfer learning technique in order to achieve superior results [3].

Image acquisition, resizing and adaptive thresholding-based pixel enhancement, feature extraction using the DL-model, classification through SoftMax, selection of the top two DL-model's results based on its accuracy, and development of fused features using serial features integration after 50% dropout are the phases that comprise this DL-system. At the end of the process, classification is performed using threefold cross-validation. The purpose of the proposed research is to evaluate the efficiency of the DL-scheme by making use

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of the unique characteristics of VGG-models and ResNet-models [4,5].

The value of this study lies in the fact that it took into account the pre-trained processes in order to obtain the required results. This makes the process of determining the state of the teeth from the digital photos that were considered straightforward and effective. When applied to picture data, the employment of both the traditional method and the fused deep-features based method contributes to the achievement of improved results. For the purpose of the inquiry, this work took into consideration 1600 images for each category, and the outcomes that were obtained through the procedure of cross-validation were recorded and examined. It is confirmed that the fused-features based detection with Soft-Max helped to achieve an accuracy of more than 97%, which demonstrates its significance on the digital tooth data that was analyzed. This instrument will be able to be utilized in the future to validate the actual tooth photos that were collected from the patients.

The main contribution of this research includes;

(i) Suggestion of a straightforward DL-system for analyzing tooth images,
(ii) Categorization of tooth data into early/advanced caries utilizing conventional DL-models,
(iii) Creation of a fused-features based technique to enhance outcomes during the image examination task.

2 Literature review

In recent years, a number of algorithms have been created to analyze photographs in order to determine whether or not they belong to the normal or abnormal class. In addition, this method is utilized to assess a number of other medical imaging modalities belonging to a variety of categories. It is essential to have an accurate assessment of oral health in order to facilitate the timely identification and monitoring of its disorders. The significance of this topic has led to the development and implementation of a number of different procedures that make use of clinical-grade dental pictures. In prior investigations, both conventional and advanced photos were used to chronicle the assessment of dental abnormalities that were supported by digital photographs taken with a DL-tool. These studies contribute to the identification of abnormalities by utilizing computer algorithms to implement segmentation and classification methods through the use of computer programs [6].

The estimation of dental caries by the use of DL-based segmentation is described in depth in a number of publications. In these works, the combination of digital images and ground-truth data is what produces the crucial result for caries analysis. Within the body of literature, the classification of dental pictures through the utilization of the chosen method is studied in conjunction with a specified technique. Additionally, the proposed research made it easier to diagnose caries with a higher degree of precision. For the identification of caries, technologies that are based on digital photography are not only straightforward and effective, but they also have the potential to serve as an alternative to manual examinations performed by a dentist. The results that were acquired via the use of computerized technologies are then validated by the dentist, and this validation is of assistance in the process of planning and carrying out the treatment [7,8].

The purpose of this research is to develop a DL-based approach that will improve the accuracy of the procedure for examining TC. The DL-approach was taken into consideration for the single tooth image examination technique included in this research. This procedure requires manual labour for cropping and supplying the image. Due to the fact that the DL-system that was built is efficient, the detection accuracy has been significantly enhanced. In situations that take place in real time, the digital camera is positioned on the tooth that has been identified as abnormal, and the image that is acquired is then processed using the DL-scheme. This methodology is an improved method that can be easily used to photos received from actual patients due to its convenient implementation.

3 Methodology

The approach that was designed to analyze the photos using the DL-model is demonstrated in this section of the research. The DL-scheme that was taken into consideration for the TC recognition is presented, and this section also provides the necessary information from the collection of tooth images to the evaluation. Specifically, as can be seen in Figure 1, this architecture is composed of two distinct portions. The first part consists the gathering of the tooth picture that contains caries and labelling it by the dentist, and the second phase involves the pre-processing and storage of these images in the database for use in the future.

The photographs that are contained within the database are taken into consideration in this research, along with the required labelling. After that, the images are resized to 224x224x3 pixels and enhanced by employing the adoptive thresholding technique in order to achieve better detection results. An inquiry into TC necessitates the extraction of features via the utilization of DL-models and the classification of data through the utilization of SoftMax methodology. Following the determination of the two most effective DL models, the development of a fused-features vector is brought about. A combination of individual and fused features is utilized in order to assess the functioning of the system. 1200 photos were examined for each category for the purpose of this study, and the number of features involved in this classification task is comparable to the number of features involved in the typical deep-features. The CM and ROC are the outcomes of this endeavour; the CM makes a contribution to the computation of the fundamental metrics based on the TC, and the final result is validated to confirm that the labour was worthwhile.

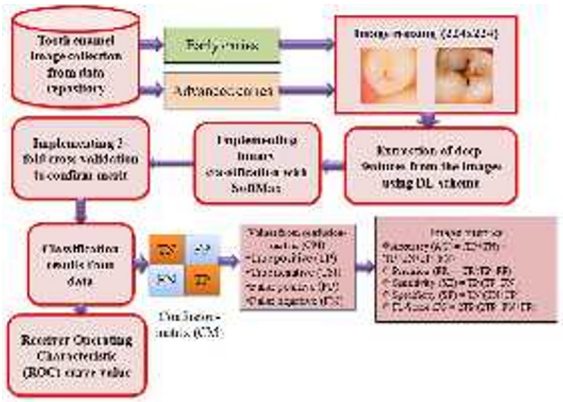


Fig. 1. Proposed architecture to detect tooth abnormality

3.1Tooth image data

One of the most important clinical procedures is the identification of abnormalities in digital images for the purpose of illness detection. The digital pictures of teeth that were obtained from [9] are utilized in this work for the purpose of conducting an inquiry using the DL-model. The photos have already been classified as early and advanced caries, and those classifications were analyzed using a classification system based on SoftMax. In the first place, the adaptive thresholding approach is taken into consideration in order to enhance the pixel information once these photos have been resized to 224x224 pixels. Following that, the enhanced image is employed in this investigation, and the data split that was performed as well as the sample images that were taken into consideration for this investigation are displayed in table 1 and Figure 2, respectively.

Fig. 2. Sample images from the database

Table 1. Tooth image data for examination

Image class	Tooth images for the evaluation			
	Total	Train	Validate	Test
Early	1500	1200	150	150
Advanced	1500	1200	150	150

3.2Deep learning scheme

The selection of an appropriate computer algorithm is essential for assessing the effectiveness of the developed system. This study examines pre-trained deep learning models frequently utilized in contemporary research. To assess the model's validity, it is essential to identify an appropriate scheme and subsequently evaluate its merit based on the classification results. This research evaluates common DL-model named EfficintNet (EN) models [10,11] for the analysis and their performance assessed through binary classification. To enhance the outcomes of this scheme, the following parameters are designated for these models: monitoring values include accuracy and loss, activation function is ReLU, optimizer is Adam, pooling method is max, learning rate is set at 1e-4, batch size is 8, and the classifier employed is SoftMax [12].

3.3 Features fusion and classification

In many data examination tasks utilizing the DL-scheme, analyses based on individual features often yield suboptimal results. Consequently, modified features, such as fused and ensemble features, are frequently employed to enhance outcomes. This study examined the FF-based analysis frequently addressed in the literature. The development of the FF involves identifying the most effective DL models based on accuracy achieved during the SoftMax classification task. Subsequently, the features of these models are reduced by 50% after ranking, and the two sets of features are serially combined to create a single FF, which is then utilized for classifying the image data in question. This feature fusion method is effective in achieving improved detection results on image data, outperforming detection based on individual features, which is typical in conventional deep learning scheme implementations [13,14].

3.4 Performance verification

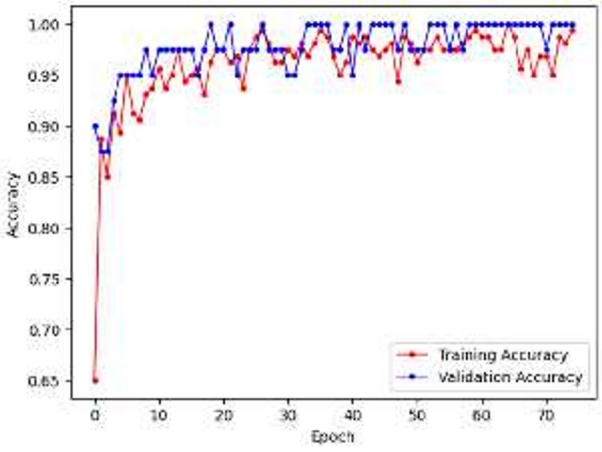
The analysis conducted using the Python program indicated that the developed DL-scheme was effective for the image database utilized. This action was undertaken to obtain additional information. The computer is equipped with an Intel Core i5 processor, 20GB of RAM, and 4GB of VRAM. The verification process utilizes image performance data obtained from CM and ROC-curve analysis. The results of the study indicate that the employed strategy enhances caries detection outcomes through the utilization of digital image databases. The study's conclusions presented this evidence.

4 Result and Discussion

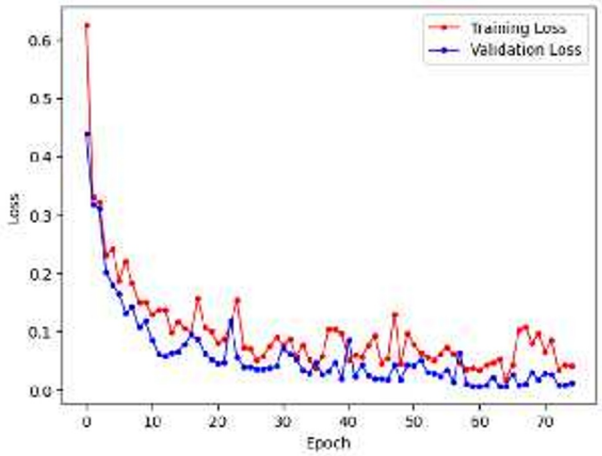
This section presents and analyzes the experimental inquiry conducted to utilize the recommended DL-tool. The initial phase of this investigation involves the application of individual feature-based detection, followed by the subsequent phase of implementing DL-based classification. The ENB0 model is initially considered prior to the application of the SoftMax algorithm for classifying the tree image database. Figure 3 presents the results of the training and validation conducted over 75 epochs. Figures 3(a) and (b) illustrate the accuracy and loss achieved through the application of this strategy. Figure 4 presents the outcomes derived from the application of various layers of the ENB0 model to a sample image, illustrating the transformation of pixels into features. The layers 1 to 4 of the image are

presented in Figures 4(a) to 4(d). Figure 5 illustrates the ROC curve obtained for ENB0 during the testing process, yielding a value of 1.0000, thereby affirming the effectiveness of ENB0 on this database.

A process analogous to the previously described one is employed to validate the performance of the DL model with specific characteristics. The results derived from this procedure are displayed in Table 2. The features-based data classification utilizing SoftMax has been successfully completed with individual features and FF. The results presented in Table 3 confirm that the developed system achieves an accuracy ranging from 90% to 92% on the provided image data when utilizing the SoftMax classifier. This outcome indicates that the system effectively identifies both healthy and infected trees during the classification task implemented on this database.

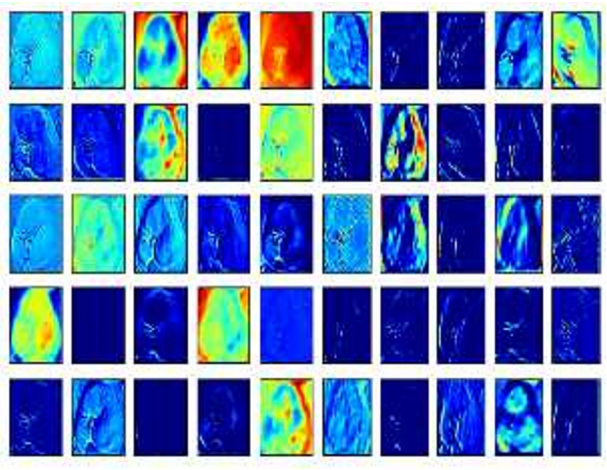


(a)Accuracy Vs Epoch

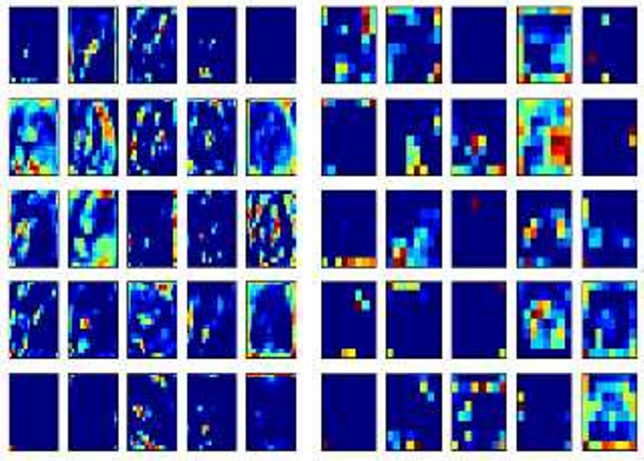


(b) Loss Vs Epoch

Fig. 3. Initial training outcome with ENB0



(a)Layer1 (b) Layer2



(c)Layer 3 (d) Layer 4

Fig. 4. Different layer results with ENB0

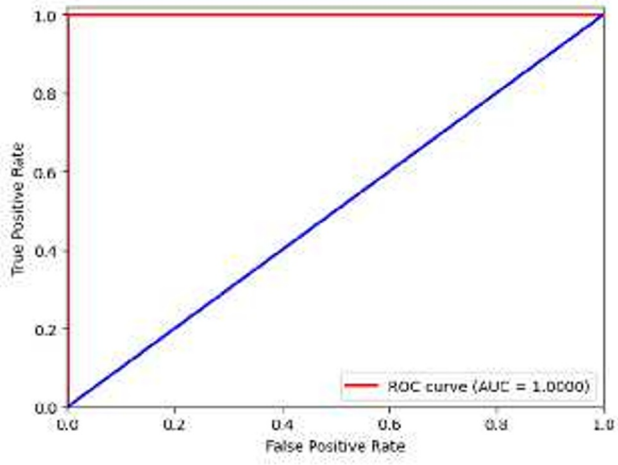


Fig. 5. Final result to demonstrate the ROC-value

Table 2. Performance evaluation of DL-scheme with individual features and FF with SoftMax

Model	TP	FN	TN	FP	AC	PR	SE	SP	FS
ENB0	136	14	138	12	91.3333	91.8919	90.6667	92	91.2752
ENB1	135	15	137	13	90.6667	91.2162	90	91.3333	90.6040
ENB2	134	16	137	14	90.0332	90.5405	89.3333	90.7285	89.9328
ENB3	136	14	135	15	90.3333	90.0662	90.6667	90	90.3654
ENB4	139	11	136	14	91.6667	90.8497	92.6667	90.6667	91.7492
ENB5	138	12	134	16	90.6667	89.6104	92	89.3333	90.7895
FF	148	2	145	5	97.6667	96.7320	98.6667	96.6667	97.6898

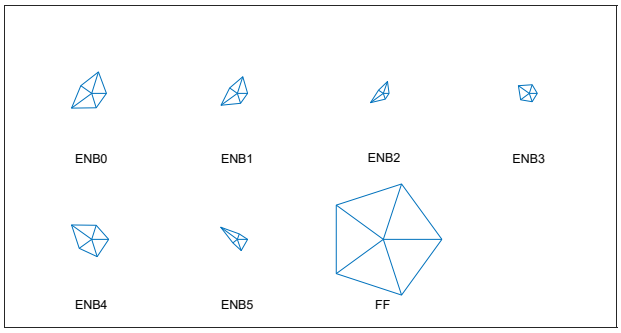


Fig. 6. Overall performance with Glyph-plot

The results presented in Table 2 confirm the efficacy of the developed system on this image database. A Glyph-plot is constructed for the values in Table 2 to illustrate the overall performance, as shown in Figure 6. This figure also confirms that FF-based detection contributes to improved results on this database. This confirms that the developed system is effective in detecting tree conditions and can be utilized in the future to evaluate thermal images obtained with an appropriate imaging system.

5 Conclusion

Dental caries are one of the most important factors that contribute to oral health. It is essential to diagnose and treat dental caries in a timely manner in order to prevent the development of infection and the loss of teeth. The effective diagnosis of tooth cavities in dental clinics needs the utilization of a variety of treatments, one of which is the visual inspection carried out by a dentist who is particularly skilled in the field. This research offered a digital photography-based examination that makes use of the DL-scheme with the intention of supporting the dentist in the detection of TC by the utilization of a method that is comparable to eye inspection. Following the completion of this examination, the results are then sent to the dentist for verification and the subsequent treatment to be carried out. It was taken into mind in this work that the TC-data with labels that were either early or advanced for the investigation were taken into account. Based on the findings of this investigation, a DL-scheme was developed by making use of pre-trained models. A level of accuracy of up to 90% was achieved by the utilization of individual characteristics in the experimental assessment that was carried out. Additionally, the detection method that was based on fused features had an accuracy of more than 97%.

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