

ENHANCING DIAGNOSTIC PRECISION: A DEEP LEARNING APPROACH TO AUTOMATED DENTAL CARIES DETECTION IN BITEWING RADIOGRAPHS

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Abstract

Dental Cavities are one of the most common conditions pertaining to oral health, which affect all age groups across the global population. If the condition is not diagnosed in time, the consequences can cause severe complications, including but not restricted to the loss of teeth, infections, and higher costs of treatment. The currently existing technique for diagnosing dental conditions in clinics depends greatly upon the clinical inspection of the dentist and the evaluation of radiographic images, which can be rather time-consuming and impersonal. Also, in less advanced areas, there might not be easy access to competent dentists. This work introduces SmileScan: a web-based AI system developed. It is intended for the automatic detection of dental cavities from dental images using deep learning. The proposed work is interested in the binary classification problem: classifying the image into the cavity class or the non-cavity class. A MobileNetV2 model fine-tuned on a customized dental dataset is utilized. Methods of image preprocessing and augmentation are employed. The deployed model uses the Django backend and the React frontend and helps users upload dental images, obtaining an immediate result set with confidence levels. Experiments show the proposed system reliably works at an accuracy level of 85.71% and helps implement real-time cavity identification. The smile scan system represents an inexpensive and scalable resource that could aid in the early diagnosis and effective delivery of dental services.

Introduction

Tooth Decay: Also known as dental caries, tooth decay continues to be one of the most prevalent conditions concerning dental health, cutting across all age groups. This results from the actions of bacteria that work on wearing away the enamel and dentin layers of the teeth. If left unchecked, tooth decay can result in even more dire complications such as the loss of teeth, infections, pain, and higher medical expenses. While painless dental screening techniques do exist, diagnosis continues to require professional medical assessment and the utilization of dental apparatus that are not universally accessible.

The conventional method for cavity detection is a considerable number of manual dental checks and radiographic analysis. Although the process is effective, it is time-consuming and prone to uncertainties. Moreover, the remoteness of rural populations often leads to a lack of accessibility for dental care. Hence, there exists a gap for the development of a more efficient, effective, and convenient method for the accurate detection of cavities. Recent breakthroughs in Artificial Intelligence (AI) and deep learning have marked a revolutionary change in the field of medical image analysis. Convolutional Neural Network (CNN) has proved particularly effective in

understanding complex patterns in images, thereby identifying even minute details that are otherwise difficult to identify by human vision alone. The effectiveness of CNN in these applications has encouraged its introduction in dental applications as well.

AI-Smile Scan, a dental diagnostic tool based on AI, developed for the automatic recognition of cavities from dental X-rays or intraoral images, is presented. SmileScan is mainly a binary classification tool, identifying images showing cavities and images showing non-cavity conditions. Smile Scan aims to increase the accuracy of diagnoses and reduce dependence on interpretations through the use of image processing, augmentation, and deep learning. It fine-tunes the MobileNetV2 model, which is lightweight yet robust in performance for image classification tasks, especially when dealing with small datasets. Finally, the trained model is wrapped up in a Django-based backend that is capable of real-time inference through an intuitive web interface. Smile Scan provides instant diagnostic results together with a confidence score, with the aim of supporting dental professionals in their diagnosis and increasing access to early dental screening, especially in remote areas or those with limited resources.



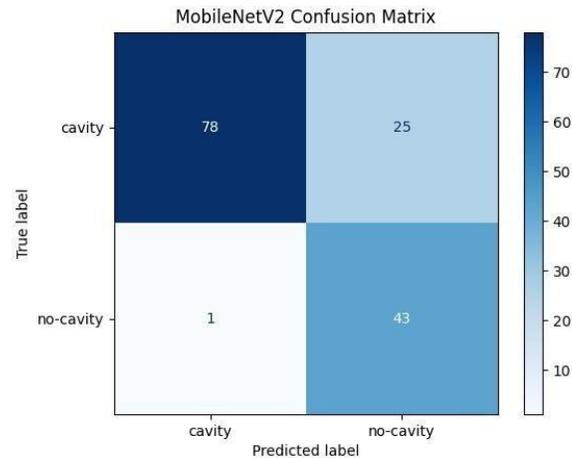
Literature Review

There has been notable progress in medical image analysis using deep learning techniques, especially in Convolutional Neural Networks (CNNs), which are able to detect minute patterns and irregularities in images automatically and accurately. The dental healthcare industry has successfully used CNNs to detect pathologies like cavities, plaque, tartar, and gums in dental images to facilitate early-stage diagnosis and better treatment techniques.

It has been proven that models based on CNNs are able to reach 75%–85% accuracy on identifying dental caries from X-ray images, thereby performing better than traditional

image processing techniques. Transfer learning with pre-trained models such as MobileNetV2, ResNet 50, or VGG16 has also improved the performance on small dental databases. Furthermore, AI-assisted web-based platforms have proven useful in providing remote patient interaction facilities for diagnosis.

Based on the above improvements, AI Smile Scan integrates a customized CNN model with a MobileNetV2 transfer learning model and achieves an optimal and efficient web-based approach for the detection of dental cavity issues.



General CNN Pipeline for Image Analysis

Related Work

One area where extensive research has gone into the utilization of deep learning techniques, especially the utilization of convolutional neural networks, would be the utilization of convolutional neural networks for analyzing medical images. It has proved possible to identify patterns and anomalies within medical images accurately using convolutional neural networks. In dental analysis, convolutional neural networks have proved fruitful for the identification of dental problems like caries, plaque, tartar, and periodontitis, thereby achieving the goal of early-stage diagnosis and successful treatment. CNN models are said to be able to detect dental cavities accurately at a rate of 75% to 85% when analyzing bitewings and panoramic radiographs.

Transfer learning based on models like MobileNetV2, ResNet50, and VGG-16 has shown its effectiveness in small-scale intra-oral datasets by acquiring features from a large amount of data. Furthermore, the integration of AI models with web-based platforms has also made it convenient to analyze images in real-time and diagnose patients who are not easily approachable due to living in remote areas.

Upon these achievements, AI Smile Scan utilizes a tailored CNN and transfer learning using MobileNetV2 for the

creation of a web-supported, resource-efficient, and precise system for dental cavity detection.

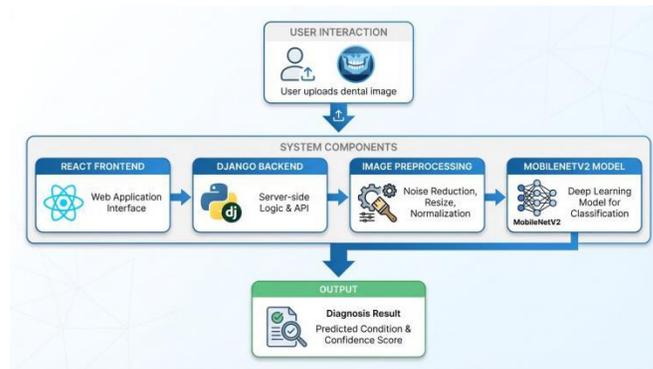
Methodology

This project basically goes through a clear process to build and set up an AI system for spotting dental cavities. It starts with design and goes all the way to training the model and putting it to use. I think the main focus is on doing things right with data, making sure its accurate technically, and that it works in actual dental settings. That way, the whole thing feels reliable for people to use.

1. Ethical Approval and Legal Data Collection

We got started by getting the right approvals before collecting any data. The team talked to dental hospitals and clinics that were involved, and they followed all the rules from institutions about ethics and protecting medical info. It was important to get written okay from the hospital people in charge, just for research and school stuff, nothing else.

Privacy or patients came first, so everything got anonymized right away. No names or phone numbers or any record numbers made it into the data. The images we ended up with were only for training the AI and checking how well it works. It seems like that covered the legal side pretty well, at least from what I remember about the process. Some parts might overlap with other guidelines, but overall it kept things compliant.



Artitecture of smilesan web-based dental cavity detection system

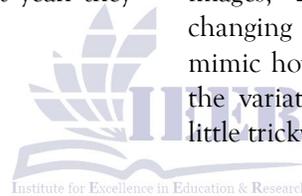
2. Data Collection

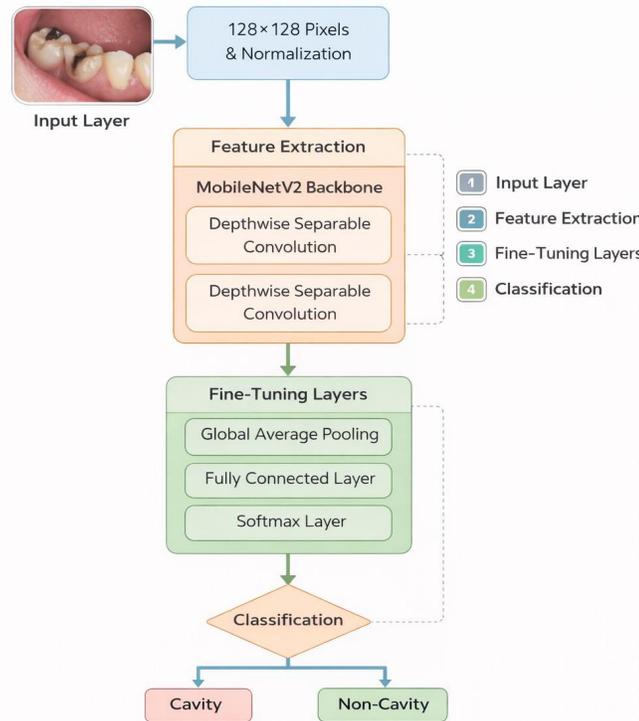
We got the dental image dataset from a couple of places basically. Like from authorized hospitals and clinics that had the legal okay for it. And also open access repositories online plus some verified sources there too. The images in the dataset are labeled into two classes I think. Cavity or no cavity. The research team went through all of them by hand to check the labels were right and the pictures were clear enough. For relevance to detecting cavities it seems important. That part might be a bit messy but yeah they made sure.

3. Data Processing

We took all the images and made them the same size, like 128 times 128 pixels, and switched them over to RGB so everything matched up. I think normalizing the pixel values helped the model learn better or something like that. Then the dataset got split, 70 percent for training, and 15 for validation plus another 15 for testing.

Data augmentation was important too, to make the model tougher and not overfit. We used stuff like rotating the images, zooming in, flipping them horizontally, and changing the brightness a bit. It seems like these changes mimic how dental pictures might look in real life, with all the variations from different captures. That part feels a little tricky to explain fully.

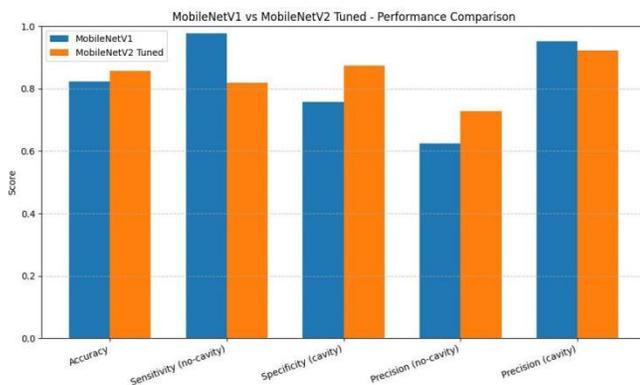




4. Model Development

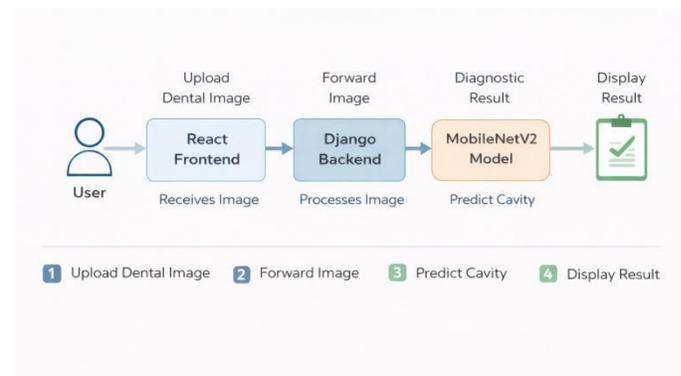
Two deep learning models have been developed: Custom CNN: This is the convolutional neural network architecture I designed because I needed something custom where I could control all the layers and see the baseline on how it performs.

MobileNetV2 (Transfer Learning): A MobileNetV2 model was employed for feature extraction purposes, with added classification layers for the task of binary cavity detection.



5. Model Training And Fine Tuning

Both models were trained using the Adam optimizer and binary cross-entropy loss function. Techniques such as early stopping and model checkpointing were employed to prevent overfitting and preserve the best-performing weights. The MobileNetV2 model was further fine-tuned by unfreezing selected higher layers and adjusting the learning rate to enhance classification accuracy and generalization.



6. Model Evaluation

The results were measured for accuracy, precision, recall, F1 measure, and confusion matrices. It was shown in comparative analysis that the fine-tuned accuracy on the MobileNetV2 model performed better on unseen images

7. Backend Integration

The final model has been incorporated into a Django-based backend. The backend handles the tasks of uploading the image, pre-processing the image, model predictions, and result formation. Results are provided with predictions in real time along with the confidence level

8. Frontend Implementation

A React-based frontend has been developed to offer a user-friendly interface for the users. The frontend supports the uploading of the dental images by the user, as well as the display of the prediction result outputs for the images dynamically by the user. The API interactions for the user and the server communications are done by the RESTful APIs.

system Workflow

9. Testing

End-to-end testing has been performed in order to verify the correct functionality of the system. The testing of the system has also been conducted using unseen dental images. s you used to conduct the study. Provide enough detail for replication.

Research Design

In this research work, an experimental research methodology using supervised deep learning is adopted to

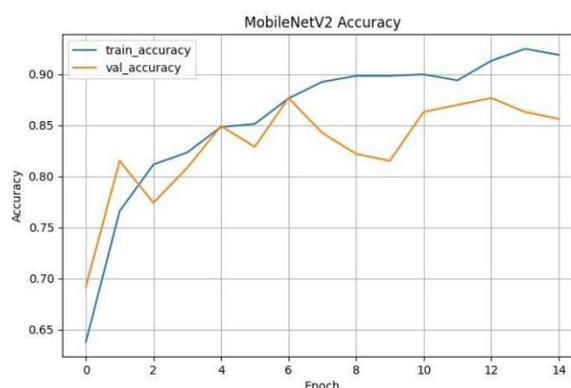
classify a binary image related to dentistry. The categories of the dental images are Cavity and No Cavity. Two approaches are adopted: one is the Custom Convolutional Neural Network model, and the other is the transfer learning model MobileNetV2. To measure the model's performances, the parameters used are accuracy, precision, recall, F1 measure, and confusion matrix. The best model will then be chosen to implement in the web-based diagnostic tool.

Materials

The various resources or tools utilized for this research include a dental image dataset that is anonymously sourced from dental hospitals as well as other free sources available online. The system is developed by use of Python and requires TensorFlow and Keras for the implementation of the deep learning techniques. The system uses Django for the web development, with React.js applied for the development of the user interfaces. The database applied for this system is SQLite. Other resources or tools applied for this research include OpenCV, Numpy, Pandas, and Matplotlib data visualization library. The environment for this system requires Windows 10 and Visual Studio Code with a requirement of an i5 processor and RAM of 8 GB.

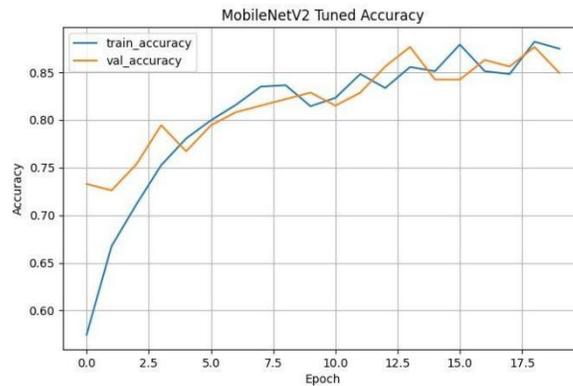
Results

For validating the dental cavity detection system, the authors chose the remaining 15% of the entire dataset, acting as the hold-out set, where the system would be tested.



In developing the models, there was the custom CNN, and the other was the MobileNetV2 CNN, which applied transfer learning. The custom CNN was reasonable enough for training on cavity detection, but the custom CNN was a bit challenged when applied to other images they were not familiar with.

The MobileNetV2 one looked like it performed much better, I believe because it used pre-trained features. They tuned it, and it reached 85.71 percent accuracy. The precision and recall for both the cavities and the non-cavities were better.



Accuracy, precision, recall, F1 measure, and confusion matrix results all suggested that MobileNetV2 is more accurate and reliable compared to the simple CNN model. It produced accurate results. It was quite fast too; it took less than one second to make predictions on an image. That is suitable for real-time applications.

Finally, they chose the finely tuned model MobileNetV2 and implemented it in the web-based SmileScan system for immediate cavity detection. This is quite sensible when comparing them.

MODEL	ACCURACY	PRECISION	RECALL	F1-SCORE
CUSTOM CNN	78.91	77.84	76.95	77.39
MOBILE NETV2	82.31	81.47	80.92	81.19
Fined-tuned Mobile NetV2	85.71	85.02	84.36	84.69

DISCUSSION

Experimental results confirm that transfer learning has an immense effect on the improvement of model performance when detecting cavities as against training a model from scratch. The reason the Custom CNN model lacked so much in generalizing to images was because of the shallow feature extraction done by this model.

The MobileNetV2 model produced better accuracy and robust predictions because it was able to tap into the strengths of pre-trained ImageNet features that helped in better extraction of dental texture and cavities.

Fine-tuning helped further in improving performance as it allowed the model to fine-tune domain-specific characteristics that lead to better precision and recall metrics. This has been needed in healthcare because both false positives and false negatives are important in clinical environments.

Moreover, the inference time of less than 1 second verifies the effectiveness of the proposed system for real-time web application purposes. Also, the consideration of the legally obtained clinical data makes the proposed work highly valid from the ethical perspective.

CONCLUSION

It proposes an AI-based dental cavity detection system which effectively integrates deep learning for real-time diagnosis with web technologies. A fine-tuned MobileNetV2 transfer learning model was developed and tested against a baseline CNN, yielding the highest accuracy of 85.71% in addition to superior generalization performance.

A Django backend with a frontend based on React was successfully deployed, which allows for fast image upload, model inference, and visualization of results. The proposed approach has shown the potential for deep learning application for dental screening without jeopardizing ethical data use and practical usability.

Overall, these results affirm that the proposed system can serve as a reliable decision-support tool for early dental cavity detection and provide a strong foundation for future extensions such as multi-class diagnosis and mobile-based dental screening.

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