Deep Metric Learning For Teeth Classification

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Abstract- *The proposed system is a deep learning-based dental image classification tool that uses deep metric learning techniques for accuratedental conditions identification, such as cavities, implants, fillings, implanted teeth, Impacted Teeth, and root canals play a critical role in the early diagnosis and treatment planning in dentistry. This project proposes an automated, deep learning-based solution for teeth classification using image processing and deep metric learning techniques. Leveraging DenseNet121, the system is trained to detect and classify various dental conditions identification with high accuracy. The classification is achieved through a well-defined pipeline involving image preprocessing, segmentation, image splitting, and feature extraction, enabling the model to handle variability in image quality and tooth structure.The system is deployed as a user-friendly web application built using Streamlit, allowing users to register, log in, and upload dental images for instant classification results. The application processes the image, classifies the dental condition, and displays performance metrics such as accuracy, confusion matrix, and ROC curve. This solution aims to assist dental professionals, researchers, and, in forensic cases, by providing an accessible tool for image-based dental condition identification, thus enhancing clinical decision-making through automated and efficient image analysis.*

Keywords- Receiver Operating Characteristic(ROC)

I. INTRODUCTION

Deep Metric Learning (DML) is an advanced paradigm in deep learning that aims to learn meaningful distance metrics between data samples by embedding them into a space where similar inputs are located close together and dissimilar ones are spaced apart. Unlike conventional classification methods that predict discrete labels, DML focuses on capturing the underlying relationships among data points based on similarity. This is achieved through specialized loss functions such as contrastive loss, triplet loss, and their variants, which train neural networks to bring similar samples closer and push dissimilar ones apart in the learned embedding space. DML has demonstrated significant success in domains like face verification, image retrieval, and biometric authentication. In the healthcare field, particularly in dental imaging, DML can be leveraged to compare radiographs, identify similar anatomical patterns, or assist in diagnosis by finding analogous cases from large databases. For example, it can help match dental X-rays to previously seen patterns of cavities, fractures, or implants, improving the efficiency and accuracy of computer-aided diagnostic systems. With its ability to handle and operate effectively in scenarios with limited labeled data, Deep Metric Learning ensures a promising approach for future dental condition classifications.

Tooth Cavities, medically termed dental caries, are a chronic, progressive condition that represents exceptionally prevalent and impactful oral health issues worldwide. They occur when the hardtooth’s outer surface, known as enamel, is gradually destroyed by acids produced through the bacterial metabolism of dietary sugars. This microbial process is primarily driven by Streptococcus mutans and other acidogenic bacteria that thrive in dental plaque, a sticky biofilm that adheres to the tooth surface. When oral hygiene is neglected, or dietary habits include frequent intake of fermentable carbohydrates (like sugar), the pH in the mouth drops, leading to demineralization of the enamel. If not treated early, this demineralization process continues into the dentin and pulp, resulting in pain, infection, and even tooth loss. Globally, the World Health Organization estimates that an average of 2.5 billion people suffer from caries in their permanent teeth.

A dental filling,it’s an essential restorative treatment to restore a tooth’s structure due to decay, trauma, or wear that damages the tooth. The process involves removing the decayed portion of the tooth and replacing it with a filling material that seals the tooth to prevent further damage or infection. These are most commonly used to treat cavities caused by bacterial plaque accumulation, which breaks down food particles, especially sugary substances, creating acids that erode the enamel and create cavities. Additionally, fillings can be used to restore teeth that have cracked or fractured due to injury or excessive wear, helping maintain their strength and appearance. Regular brushing, flossing, and visits to the dentist for professional cleanings and early cavity detection can significantly reduce the need for fillings. Globally, millions of fillings are placed each year, with more than 175 million fillings placed annually in the United States alone.

Studies show that nearly 90% of adults will have had at least one cavity filled by the time they reach adulthood. Dental Implantis a modern and long-lasting solution that consists of a titanium post surgically that has been embedded into the jawbone that acts as an artificial root. This fusion of implant with the bone through a process called osseointegration provides a stable foundation for a dental prosthesis that includes a crown, bridge, or denture. Tooth loss, which necessitates implants, can result from advanced dental decay, untreated gum disease, traumatic injuries, failed root canals, or even congenital conditions where teeth fail to develop. Impacted tooth, a dental issue where a tooth fails to emerge from the gum line properly, typically due to insufficient space in the mouth, an abnormal growth angle, or genetic factors. The most common instance of impacted teeth occurs with wisdom teeth are the third molars that usually emerge in late adolescence or early adulthood. These teeth often become impacted because they don't have enough space or due to their growth at odd angles, causing them to become trapped beneath the gum tissue. While wisdom teeth are most frequently impacted, other teeth, including canines and premolars, can also be affected. Root Canal, a dental procedure aimed at treating infection or damage to the pulp, the soft tissue at the tooth'scenter. This procedure is necessary when the pulp becomes infected or inflamed due to deep tooth decay, trauma, repeated dental work, or cracks in the tooth. Thepulp's infection can cause severe pain, swelling, and an abscess, which could lead to the spread of infection to surrounding tissues. Theprocedure of the root canalinvolves removing the infected pulp, cleaning the root canals, and, to prevent further infection and damage, scaling of the tooth is done. In most cases, a crown is placed over the treated tooth to restore its shape and function, as the tooth may become weakened during the procedure.

In recent years, artificial intelligence (AI) and deep learning have shown enormous strength in the field of medical diagnostics, including dentistry. The growing need for accurate and efficient diagnostic tools has led to the development of automated systems that can assist dental professionals in identifying various dental conditions. Traditional methods of dental diagnosis, including dental X-rays or image's visual inspection and manual interpretation that are often subject to human error and inconsistency. To address these limitations, computer vision-based approaches are increasingly being explored for dental image classification and analysis.Deep learning, particularly DenseNet 121, has revolutionized the way images are processed and analysed. These networks can automatically learn features from large datasets, enabling accurate classification of complex patterns, such as those found in teeth and dental structures. In this project, deep metric learning techniques are used to enhance the performance of DenseNet 121 models in dental conditions classifications such as cavities, implants, fillings, root canals, and implanted teeth. By training on labeled datasets and extracting meaningful features, the model learns to distinguish between subtle differences in dental images.Image preprocessing is critical to the success of deep learning models in medical imaging. Preprocessing steps such as image resizing, grayscale conversion, noise removal, and normalization help standardize the input data. Additionally, Feature extraction is performed.Segmentation techniques are also used in identifying important regions in the images that allow the model to focus on key features related to dental anomalies.

To make the system user-friendly and accessible, a web-based application is developed using Flask. This application allows users to upload dental images, view classification results, and track system performance. The combination of a deep learning-based backend with a simple graphical interface ensures that both experts and non-experts can use the system effectively. By automating the classification process, this project aims to support dental professionals with faster, more reliable diagnostic tools and contribute to the growing field of AI-driven healthcare solutions.

II. LITERATURE SURVEY

The Deep learning models, nnU-Net and DenseNet121, effectively detected and classified dental caries on panoramic radiographs with performance comparable to expert dentists, highlighting their potential for clinical diagnostic support[1].The study benchmarked 216 deep learning models for segmenting tooth structures in dental bitewing radiographs, using combinations of six architectures and twelve encoders. Results showed that models initialized with pretrained weights (ImageNet or CheXpert) performed significantly better than those with random initialization. Interestingly, simpler models like those based on VGG were more robust, and deeper models did not always yield superior performance. This highlights the importance of task-specific benchmarking and suggests that less complex, pretrained models can be effective for dental applications[2].To investigate the current developments of Artificial Intelligence (AI) in teeth identification on Panoramic Radiographs (PR). Our aim was to evaluate and compare the performances of Deep Learning (DL) models that have been employed in the execution of this task[3].This study addresses the challenge of limited dental care access in developing countries by proposing a modified DenseNet-121 deep learning model for classifying common oral diseases using a small dataset. By applying transfer learning and fine-tuning techniques, the model achieved 95% accuracy, significantly outperforming previous methods. The results highlight the potential of deep learning in improving oral diagnostics in low-resource settings, though further validation with larger datasets is needed[4].A systematic comparison of techniques for accurate prediction of dental disease through X-ray imaging. This study aims to develop an automated system for classifying dental X-rays into categories like fillings, cavities, and implants. The system seeks to improve diagnostic accuracy and reduce human error in interpreting X-ray images. It ultimately enhances the efficiency of dental professionals by automating the process[5].This study uses convolutional neural networks (CNNs) to identify dental lesions in digital X-ray images. Four CNN models were tested, with DenseNet-121 achieving the highest accuracy of 99.5%. The results show that CNNs can efficiently and accurately assist in diagnosing dental diseases[6].This study developed a deep learning-based model for detecting missing teeth positions from CBCT images using pretrained CNN models. DenseNet169 showed the best performance with a precision of 0.98 and an accuracy of 93.3% for segmentation. The findings suggest that this model could be a valuable tool for automating dental implant planning[7].This study developed a deep learning model, PDCNET, for diagnosing various dental conditions such as tooth decay and periodontal disease using dental radiographs. The model achieved impressive results with 99.79% AUC, 98.39% recall, and 98.39% accuracy, outperforming baseline models like EfficientNet and DenseNet. The findings highlight PDCNET's potential to assist dentists in accurately diagnosing dental diseases[8].A Systematic Mapping. This study reviews the use of deep learning in dental radiographs for detecting and classifying oral diseases, with a focus on models like U-Net, Mask R-CNN, and DenseNet-121. Analyzing 69 articles from 2012-2023, it highlights common challenges such as limited datasets and inconsistent methodologies. The study emphasizes the need for standardization and more detailed reporting in research[9].This study compares four advanced pixel-based segmentation models—U-Net, FPN, PSPNet, and LinkNet—using ten backbones for detecting impacted teeth in panoramic radiographs. U-Net with EfficientNetB7 achieved the highest performance with an IoU of 85.29%. The findings offer practical insights for improving dental diagnostics through AI-driven solutions[10].IDD-Net, a deep learning model using panoramic X-rays, was developed for automatic dental disease detection. Compared to models like AlexNet and Xception, it outperformed them with 98.99% accuracy and 99.97% AUC. DenseNet-121 was also evaluated, reinforcing CNNs' effectiveness in dental diagnostics[11].This study presents an explainable deep learning approach for detecting dental caries using oral images. Pre-trained CNNs, including DenseNet-121 and VGG-16, were evaluated with image enhancement techniques. VGG-16 achieved the highest accuracy (98.3%), highlighting the method's potential for accurate and interpretable diagnostics[12].This study presents a hybrid deep learning approach for detecting abnormal teeth in panoramic X-rays, as part of the DENTEX Challenge 2023. The Vision Transformer (ViT) achieved 97% accuracy, while a U-Net + SVM hybrid reached 99% with fewer parameters. These results highlight AI's promise for efficient and accurate dental diagnostics[13].A Deep Learning Approach Using EfficientNets. Deep learning is transforming dental diagnostics by enhancing the accuracy of detecting conditions like cavities, missing teeth, and periodontal disease through X-rays and CBCT images. Models such as DenseNet121, EfficientNet-B5, and custom networks (e.g., PDCNET, IDD-Net) outperform traditional methods, especially when supported by data balancing techniques. While results are promising, issues like limited public datasets and inconsistent reporting still pose challenges to clinical integration[14].In oral healthcare, deep learning is reshaping disease prediction by enabling more accurate analysis of images and patient data. It helps identify patterns that might be missed by dentists, improving early diagnosis and treatment. While challenges like limited datasets and model interpretability remain, deep learning holds strong promise for advancing oral health outcomes[15].This study develops a deep learning model for automatic tooth detection, numbering, and caries identification in bitewing radiographs. Using a three-stage pipeline with CNN and YOLOv7, the system achieved high performance in detecting teeth (F1-score: 0.99) and caries (F1-score: 0.822). The model offers real-time support for dental diagnostics, improving treatment efficiency[16].This study develops an explainable deep learning model for detecting dental caries from panoramic images. The model, tested with EfficientNet-B0, DenseNet-121, and ResNet-50, achieved high accuracy, with ResNet-50 performing best (92% accuracy, 87.33% sensitivity). The heat maps generated by the model enhance explainability, helping dentists validate results and improve diagnostic accuracy[17].This study develops a deep learning-based system for the autonomous identification of dental implant brands using panoramic radiographs. A total of 28 deep learning models, including CNN and vision transformer architectures, were evaluated on a dataset of 1258 radiographs from six implant manufacturers. The ConvNeXt model achieved the highest accuracy of 94.2%, demonstrating the potential for integrating deep learning into clinical practice to improve diagnostic accuracy and treatment outcomes in implantology[18].This study explores the use of deep learning (DL) for automatic feature detection, segmentation, and quantification in periapical radiographs (PRs). The U-Net architecture, especially when paired with DenseNet121, performed best in validation (mIoU = 0.501), although performance declined on the test set (mIoU = 0.402). The study highlights the potential of DL for automated PR analysis but suggests that more research and larger datasets are needed, especially for challenging cases like interradicular radiolucencies[19].This review examines deep learning models for caries detection, including DenseNet-121, across various dental imaging types. Of the 42 studies reviewed, diagnostic accuracy ranged from 68% to 99%, with DenseNet-121 showing notable performance. Although study quality varied, deep learning, including DenseNet-121, proves useful as a tool for assisting in the detection of carious lesions, potentially improving diagnostic accuracy in dental practice[20].This study assesses EfficientNet-B0 for classifying dental caries in tooth images. With a dataset of 6348 images, EfficientNet-B0 achieved 0.98% accuracy, comparable to MobileNetV2, but less than ResNet-50 (0.99%). Despite this, it used significantly fewer parameters, demonstrating efficiency. EfficientNet-B0 shows promise for enhancing dental caries classification and clinical decision-making[21].This research explores the use of deep learning (DL) to classify maxillary canine impaction types from panoramic dental radiographs, specifically using the Yamamoto classification. Four models—DenseNet-121, VGG-16, Inception V3, and ResNet-50—were developed. The results show that Inception V3 outperformed the other models with an accuracy of 0.9259. This automated classification system could aid dentists by streamlining the canine impaction diagnosis process, improving reliability and efficiency[22].This study explores deep learning models like Xception, ResNet, Inception, MobileNet, and DenseNet for diagnosing oral diseases, including Caries, Gingivitis, and Hypodontia. MobileNet, DenseNet, and Xception achieved the highest accuracies of 85.19%, 83.82%, and 82.70%, respectively. The findings emphasize deep learning's potential in efficient and accurate oral disease diagnosis using medical image analysis[23].This study proposes a deep fusion model for classifying dental caries using ResNet 50, MobileNet V2, and DenseNet 121 to extract distinct features from periapical X-ray images. The combined features from these sub-models achieve an accuracy of 95.5%, recall of 95.2%, precision of 94.6%, and F1 score of 92%. The proposed model outperforms previous state-of-the-art networks in dental caries detection[24].This study introduces a transfer learning-based deep learning approach to classify six common dental diseases, enhanced with explainable AI techniques like LIME and Grad-CAM. Evaluating four pre-trained models (DenseNet169, InceptionV3, MobileNetV2, and ResNet50V2), MobileNetV2 achieved the highest performance with 89.02% accuracy, 89.45% precision, and 89.13% F1-score. The integration of XAI ensures transparency and trust in the diagnostic process, offering a reliable solution for oral disease classification[25].Deep learning models and dental diagnosis: A review: This study explores deep learning in dental diagnostics, particularly for caries and periodontal disease detection. cnns and u-net models were evaluated for enhancing accuracy. results show they outperform traditional methods, offering high precision and predictive power. these advancements enable early detection, personalized treatment, and improved outcomes, despite challenges like data needs and computational demands[26].

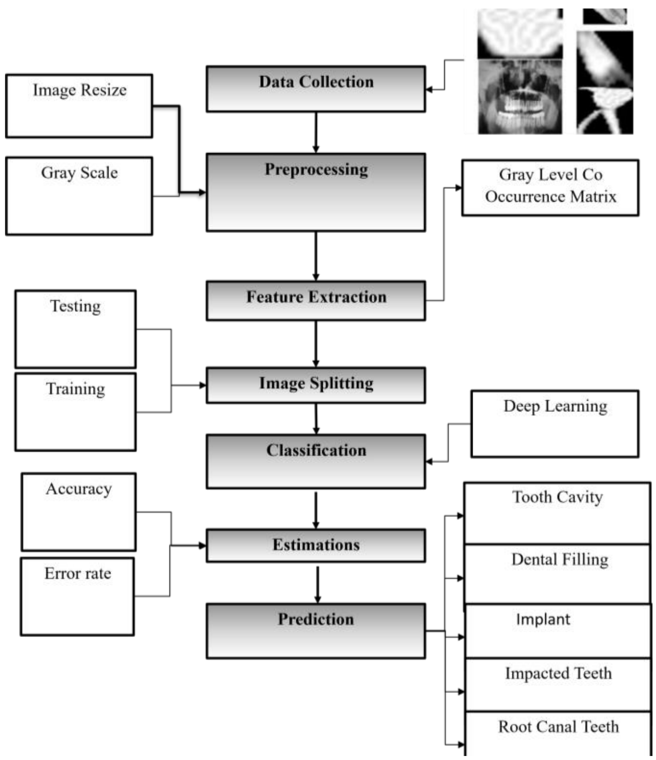
III. PROPOSED METHODOLOGY

Dental healthcare is a vital component of overall human well-being, yet manual diagnosis of dental conditions from radiographs or images can be time-consuming, subjective, and error-prone. The advent of artificial intelligence and computer vision offers the potential to revolutionize dental diagnostics through automated image classification systems. This project explores a deep metric learning approach to dental image classification, aiming to accurately identify and categorize common dental issues like cavities, implants, fillings, root canals, and impacted teeth.

With the advancement in deep learning, especially DenseNet121, it has become possible to achieve significant performance in image classification tasks. Networks like DenseNet121 have demonstrated remarkable success in extracting deep features from complex image data. In this project, these models are applied to a custom dataset of teeth images, where they are trained to recognize and distinguish between different dental categories through extensive training, preprocessing, and augmentation strategies.

A crucial step in achieving high classification performance lies in the data preparation process. This includes resizing images, grayscale conversion, noise filtering, and normalization. Furthermore, segmentation techniques using edge detection and thresholding enhance feature localization, which supports better training of deep learning models. The data is then split into training and testing sets to ensure the reliability of the evaluation process.

To make the system accessible and interactive, the entire classification process is integrated into a Flask-based web application. Users can register, log in, and upload their dental images for analysis. The system not only predicts the condition of the tooth but also displays detailed performance metrics. This project serves as a proof of concept for AI-assisted dental diagnostics, aiming to improve accuracy, speed, and accessibility in dental healthcare analysis.The primary objective of this project is to develop an intelligent, deep learning-based system for the automatic classification of dental conditions using image data. By employing advanced deep metric learning techniques and DenseNet 121, the goal is to accurately identify and categorize different types of dental anomalies, including cavities, implants, fillings, implanted teeth, and root canals. This system aims to assist dental professionals by providing fast and reliable predictions, minimizing diagnostic time and improving treatment planning.Another key objective is to integrate the classification system into a user-friendly web application using Flask, allowing users to register, log in, and upload dental images for diagnosis. The application provides instant classification results along with performance metrics such as accuracy, loss, confusion matrix, and ROC curve. This makes the solution not only technically robust but also practically accessible for both clinical and educational environments.



Processes Involved:

i) Data Collection

To build a reliable and intelligent system for Teeth Classification, the first step involved gathering quality datasets. The image dataset was sourced from Kaggle, consisting of 209 images,167 images for training, and 41 images for testing. These images cover a wide range of tooth diseases and their treatment and have been categorized. This dataset served as the foundation for training the image-based prediction model using DenseNet 121. Each image varies in resolution and quality, so consistent preprocessing steps were necessary later to standardize the input format. Alongside the image data, a CSV file containing teeth disease-based data was used to train a complementary deep metric learning model. This dataset includes various tooth diseases and their treatments, such as Tooth cavities, Dental fillings, Dental implants, impacted teeth, and root canal teeth, along with corresponding disease labels. Each entry in the CSV represents symptoms of diseases and treatments that are commonly observed in patients suffering from dental problems. By including this dataset, the system becomes capable of making accurate predictions.

ii) Preprocessing

The Image Preprocessing module is responsible for preparing the input images for the subsequent feature extraction and classification steps. The first task involves resizing the images to a consistent dimension, ensuring that the model can process all images in a uniform manner. This step is essential because deep learning models require input images of a fixed size. The second task is noise filtering, which removes any irrelevant details or artifacts in the images that may confuse the model. This could involve techniques like Gaussian blurring to improve image quality. Grayscale conversion follows, which simplifies the image by removing color information and retaining only the intensity, helping the model focus on structural features relevant to classification.The final step in preprocessing is normalization, where pixel values are scaled to a standard range (often between 0 and 1) to ensure that the model can learn efficiently. Images with varying brightness or contrast can lead to inconsistent learning, so normalization standardizes all images. Additionally, image augmentation techniques, like random rotations, flips, and brightness adjustments, are applied to increase the diversity of the dataset, which helps in improving model generalization. These steps collectively ensure that the input images are of high quality and are consistent in terms of size, format, and characteristics, making them ideal for training deep learning models.

iii) Feature Extraction and Segmentation

This project explores a deep metric learning approach to dental image classification, aiming to accurately identify and categorize common dental issues like cavities, implants, fillings, root canals, and impacted teeth. With the advancement in deep learning, especially DenseNet121, it has become possible to achieve significant performance in image classification tasks. Networks like DenseNet121 have demonstrated remarkable success in extracting deep features from complex image data. In this project, these models are applied to a custom dataset of teeth images, where they are trained to recognize and distinguish between different dental categories through extensive training, preprocessing. segmentation techniques using edge detection and thresholding enhance feature localization, which supports better training of deep learning models. The data is then split into training and testing sets to ensure the reliability of the evaluation process.

iv)Image Splitting and Classification

The Data Splitting module ensures that the dataset is divided into training and testing subsets to train and evaluate the machine learning models effectively. Typically, an 80-20 split is used, where 80% of the data is used for training the model, and 20% is set aside for testing. This division ensures that the model has sufficient data to learn from while also providing an independent dataset to evaluate its performance. The Deep Learning Model module is the core component of the system, tasked with classifying the input images based on the features extracted and preprocessed. This module integrates several deep learning architectures, including DenseNet 121. DenseNet is particularly suited for image classification tasks as it automatically learn spatial hierarchies of features from the raw pixel data. They apply convolutional layers to detect patterns, such as edges or textures, and use pooling layers to reduce dimensionality while maintaining critical information. By training on large datasets, DenseNet can learn to classify images with high accuracy.

v) Web Interface

The system requirements include Windows 10 os, and the code is in Python language and uses Anaconda Prompt and Spyder platform for running the code. The web interface is designed with simplicity and user accessibility in mind. Upon registration and login, users are greeted with an intuitive dashboard. The website is where they can upload dental images in .jpg or .png formats. The upload process is secured, and the backend instantly begins processing the input through the integrated models. The results are displayed on the same dashboard, allowing users to view predicted disease and treatment names.

IV. RESULTS AND DISCUSSION

The proposed system for dental image classification using deep metric learning effectively addresses the limitations of traditional diagnostic methods in dentistry. Through the use of an advanced deep learning model, DenseNet121, the system can automatically classify dental images into various categories like cavities, implants, fillings, root canals, and implanted teeth with high accuracy. The structured pipeline—from preprocessing and augmentation to segmentation and classification—ensures efficient handling of images and reliable output. By integrating the backend model with a Flask-based web application, the project offers a user-friendly platform where users can easily upload images and receive instant diagnostic feedback. This not only enhances accessibility but also bridges the gap between AI technology and practical healthcare use. Overall, the project demonstrates how artificial intelligence can contribute to faster, more accurate dental diagnostics and paves the way for more intelligent medical systems. Also, it is useful forAutomated dental diagnosis, Remote dental consultations (teledentistry), and Research and data analysis.

V. CONCLUSION AND FUTURE SCOPE

Although the current system performs well on static image data, future enhancements can focus on expanding the dataset with more diverse and real-world samples, including dental X-rays of Cavity tooth, Fillings, Impalnts, Impacted Tooth, and Root canal. The integration of real-time camera support or live video analysis could make the application even more dynamic and useful in clinical settings. Additionally, adding more dental conditions and anomalies to the classification categories can broaden the system's applicability in complex diagnostics. Another promising direction is to incorporate explainable AI (XAI) methods, allowing the system to visually highlight the region of interest (e.g., where the cavity, Fillings, implants, Impacted Tooth, and Root canal are detected). This would help dentists better understand and trust the AI's predictions. Further, deploying the system on cloud platforms or mobile applications would enhance its availability and scalability, making it a valuable tool not just in clinics but also for remote consultations and dental education. it is specifically useful for dental doctors in identifying root canals, detecting the presence of cavities, classifying impacted teeth, recognizing fillings, and Furthermore, it is useful for resolving forensic cases for identifying dental implants and fillings of victim, and speeds up post-mortem dental analysis with automated classification.

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