A Project Report on

SmartDent-AI: AI-Driven Diagnosis and Treatment Solutions

Submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Engineering

in

Computer Science and Engineering(Data Science)

by

Janvi Sharma (21107032)

Under the Guidance of

Dr.Vaibhav Yavalkar
Ms.Aishwarya Londhe

Department of Computer Science and Engineering (Data Science)
A.P. Shah Institute of Technology
G.B.Road,Kasarvadavli, Thane(W)-400615
UNIVERSITY OF MUMBAI

Academic Year 2024-2025

Approval Sheet

This Project Synopsis Report entitled ***"SmartDent-AI: AI-Driven Diagnosis and Treatment Solutions"*** Submitted by ***"Janvi Sharma"(21107032)***is approved for the partial fulfillment of the requirenment for the award of the degree of ***Bachelor of Engineering*** in ***Computer Science Engineering in Data Science*** from ***University of Mumbai***.

Ms.Aishwarya Londhe
Co-Guide

Dr.Vaibhav Yavalkar
Guide

Ms.Anagha Aher
HOD, Computer Science and Engineering-Data Science

Place:A.P.Shah Institute of Technology, Thane
Date:

CERTIFICATE

This is to certify that the project entitled ***"SmartDent-AI: AI-Driven Diagnosis and Treatment Solutions"*** submitted by ***"Janvi Sharma"(21107032)*** for the partial fulfillment of the requirement for award of a degree ***Bachelor of Engineering*** in ***Computer Science and Engineering (Data Science)***,to the University of Mumbai,is a bonafide work carried out during academic year 2024-2025.

Ms. Aishwarya Londhe Co-Guide	Dr. Vaibhav Yavalkar Guide
Ms. Anagha Aher HOD, CSE Data Science	Dr. Uttam D.Kolekar Principal

External Examiner(s)	Internal Examiner(s)
1.	1.
2.	2.

Place:A.P.Shah Institute of Technology, Thane

Date:

Acknowledgement

I have great pleasure in presenting the synopsis report on **"SmartDent-AI: AI-Driven Diagnosis and Treatment Solutions".** I take this opportunity to express our sincere thanks towards our guide **Dr. Vaibhav Yavalkar and Ms. Aishwarya Londhe** for providing the technical guidelines and suggestions regarding line of work. I would like to express our gratitude towards his constant encouragement, support and guidance through the development of project.

I thank **Ms.Anagha Aher** Head of Department for his encouragement during the progress meeting and for providing guidelines to write this report.

I express our gratitude towards BE project co-ordinator **Ms.Poonam M. Pangarkar**, for being encouraging throughout the course and for their guidance.

I also thank the entire staff of APSIT for their invaluable help rendered during the course of this work. We wish to express our deep gratitude towards all our colleagues of APSIT for their encouragement.

Janvi Sharma
(21107032)

Declaration

I declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that We have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Janvi Sharma(21107032)

Date:

Abstract

SmartDent-AI is an advanced AI-powered dental diagnostic and treatment platform aimed at enhancing dental care delivery through accurate diagnostics, personalized treatment planning, and improved patient engagement. By utilizing deep learning models such as MobileNetV2 for disease detection, U-Net for image segmentation, and Pix2Pix for orthodontic treatment simulations, the platform offers comprehensive dental solutions. It accurately detects dental conditions like caries, gingivitis, and misalignment through analysis of dental X-rays and intraoral images. The orthodontic treatment feature uses a Pix2Pix model, consisting of a UNet Generator for aligning misaligned teeth and a PatchGAN Discriminator to ensure realistic image generation. The system preprocesses input images to generate visual representations of aligned teeth, aiding in treatment planning and communication between dentists and patients. SmartDent-AI integrates telemedicine tools for real-time remote consultations, allowing patients to upload images and receive AI-driven diagnostics and personalized treatment recommendations. It also facilitates easy appointment scheduling with specialists. Through its user-friendly interface and real-time processing capabilities, SmartDent-AI provides an innovative and comprehensive solution to revolutionize dental care.

Keywords: *Convolutional Neural Network(CNN), Dental Diagnostic Platform, Real-Time Diagnostics, Personalized Treatment Recommendations, Treatment Simulations,Orthodontic Treatment Simulation, Pix2Pix, UNet, PatchGAN.*

Contents

List of Figures

List of Tables

List of Abbreviations

CNN: Convolutional Neural Network

AI: Artificial Intelligence

DFD: Data Flow Diagram

CLAHE: Contrast Limited Adaptive Histogram Equalization

CBCT: Cone Beam Computed Tomography FCN Fully Convolutional Network

U-Net: U-shaped Convolutional Neural Network

GAN : Generative Adversarial Network

cGAN: Conditional Generative Adversarial Network

UNet: A type of CNN architecture used for image segmentation

PatchGAN: Patch-based Discriminator in GAN architecture

ReLU: Rectified Linear Unit

RBAC: Role-Based Access Control

HIPAA: Health Insurance Portability and Accountability Act (USA privacy standard)

GDPR: General Data Protection Regulation (EU privacy regulation)

ANN: Artificial Neural Network

XAI: Explainable Artificial Intelligence

OTP: One-Time Password

API: Application Programming Interface

DB: Database

GUI: Graphical User Interface

Zego: Refers to Zego Cloud API for video conferencing

Chapter 1

Introduction

Dental health plays a crucial role in overall well-being, but challenges such as timely and accurate diagnosis, efficient treatment planning, and patient engagement often hinder the delivery of optimal care. Traditional dental practices rely heavily on manual interpretation of dental X-rays and intraoral images, which can be time-consuming and prone to human error. Additionally, the growing demand for remote consultations and the need for more advanced treatment simulations, especially in orthodontics, require modern solutions that integrate new technologies into dental workflows.

SmartDent-AI addresses these challenges by utilizing Artificial Intelligence (AI) and deep learning techniques to assist dental professionals in making faster, more accurate diagnoses while enhancing patient communication and treatment precision. By leveraging Convolutional Neural Networks (CNNs), SmartDent-AI is capable of analyzing dental X-rays and intraoral images to detect common dental issues such as calculus, dental caries, mouth ulcers, gingivitis, tooth discoloration, and teeth misalignment. The platform also incorporates advanced treatment simulations specifically designed for orthodontic procedures, helping dentists provide more accurate treatment plans.

Beyond diagnostics, SmartDent-AI enables remote consultations through telemedicine, allowing patients to upload images for AI-driven assessments and receive personalized treatment recommendations. The platform further enhances the patient experience by streamlining specialist appointment bookings, securely managing patient records, and offering real-time progress monitoring throughout treatment. With its comprehensive approach, SmartDent-AI aims to revolutionize dental care by integrating state-of-the-art AI technology into everyday dental practices, improving both the quality and efficiency of patient care.

1.1 Motivation

The motivation behind developing SmartDent-AI is driven by the need to improve the accuracy, efficiency, and accessibility of dental care in an evolving healthcare landscape. Traditional methods of diagnosing dental issues, which rely on manual interpretation of X-rays and intraoral images, can be prone to errors, leading to inconsistent diagnoses and suboptimal treatment outcomes.

As demand for remote healthcare continues to grow, especially in underserved regions with limited access to specialists, there is a need for a platform that not only provides accurate diagnostics but also supports remote consultations. SmartDent-AI addresses these challenges by integrating AI-driven diagnostics, advanced treatment simulations, and telemedicine capabilities, enabling patients to receive care from anywhere. By enhancing diagnostic accuracy, improving treatment planning, and offering remote access to dental care, SmartDent-AI aims to bridge the gap between technology and traditional dental practices, ultimately transforming the way dental care is delivered and making it more accessible and effective for all.

1.2 Problem Statement

The dental healthcare industry faces significant challenges that hinder the delivery of high-quality patient care. Traditional diagnostic methods, which rely heavily on manual analysis of dental X-rays and intraoral images, are often time-consuming and susceptible to human error, leading to inconsistent diagnoses and ineffective treatment plans.

Moreover, orthodontic treatments require detailed planning and accurate simulations to achieve optimal outcomes, yet current practices often fall short in providing these tools. This gap in technology results in a lack of clarity for patients regarding their treatment options and outcomes. Furthermore, the need for real-time progress monitoring and secure management of patient records remains unmet in many dental practices, which complicates the overall patient experience.

To address these issues, there is a pressing need for an advanced solution that leverages Artificial Intelligence (AI) to enhance diagnostic accuracy, facilitate remote consultations, and provide detailed treatment simulations for orthodontic procedures. SmartDent-AI aims to bridge these gaps by integrating AI-driven analytics, telemedicine capabilities, and secure patient record management into a comprehensive platform, ultimately improving the quality of dental diagnostics and patient care.

1.3 Objectives

The SmartDent AI platform seeks to revolutionize dental care by integrating advanced technologies that enhance diagnostic accuracy and streamline treatment processes. This innovative approach focuses on improving patient outcomes and accessibility in dental services. To achieve this vision, the following objectives have been established:

- **To Enhance Diagnostic Precision**: Utilize deep learning algorithms, including Convolutional Neural Networks (CNNs), to accurately analyze dental X-rays and intraoral images for detecting various dental issues.

- **To Transform Misaligned Teeth Correction**: Implement a deep learning-based approach for aligning misaligned teeth using a structured pipeline. This includes preprocessing images, applying the Pix2Pix model with a UNet-based generator and

PatchGAN discriminator, and refining outputs through post-processing for high-quality transformations.

- **To Create a Seamless Appointment Scheduling System**: Develop an integrated booking system that enables patients to schedule appointments with dental specialists based on AI-generated diagnostic reports, featuring a user-friendly web interface for ease of use.

- **To Facilitate Remote Consultations**: Integrate telemedicine tools that allow patients to upload images for AI-driven diagnostics and consult with dental professionals remotely, enhancing accessibility andconvenience.

- **To Provide Treatment Suggestions**: Ensure that patients receive AI-generated suggestions for further treatment based on diagnostic results, helping them make informed decisions about their dental care.

1.4 Scope

The scope of the SmartDent AI platform encompasses various innovative features aimed at transforming dental care delivery. By focusing on advanced technologies, we aim to improve diagnostics, treatment planning, and patient engagement. The specific areas of focus include:

- **AI-Driven Diagnostics**: Focus on the implementation of deep learning algorithms to analyze dental images for the accurate identification of conditions such as cavities, gingivitis, and misalignment.

- **Orthodontic Treatment Visualization**: Explore the development of advanced treatment simulation capabilities specifically for orthodontic procedures, enhancing communication and decision-making for both patients and dentists.

- **Personalized Treatment Pathways**: Integrate a recommendation system that generates tailored treatment suggestions based on the diagnostic data, improving patient outcomes and satisfaction.

- **Telemedicine Integration**: Examine the feasibility of integrating telemedicine solutions that support real-time consultations and follow-ups, addressing the growing demand for remote healthcare services.

- **User-Friendly Appointment Management**: Evaluate and develop a robust appointment management system that streamlines scheduling and enhances the overall patient experience through intuitive design and functionality.

Chapter 2

Literature Review

This literature review explores the body of research on SmartDent AI: AI-Driven Diagnosis and Treatment Solutions, examining the key studies, theories, and findings that have shaped the field. The review provides a critical analysis of existing work, highlighting significant contributions as well as areas where knowledge remains limited or inconclusive. By analyzing the approaches and conclusions drawn by various scholars, this review aims to clarify current understandings and identify potential directions for future research.

2.1 Comparative Analysis of Recent study

For a comprehensive understanding of advancements in dental disease diagnosis, it is essential to examine the evolving role of deep learning techniques, particularly convolutional neural networks (CNNs) and transfer learning. Recent studies have demonstrated remarkable progress in the automation of dental image analysis, offering solutions for disease classification, segmentation, and detection in X-ray and CBCT images. By comparing the methodologies, results, and limitations of these studies, this analysis aims to highlight the strengths and weaknesses of various deep learning models, enabling the identification of trends and potential areas for future research.

Zuhal Can, Sahin Isik, Yildiray Anagun, "CVApool: Using Null-Space of CNN Weights for Tooth Disease Classification," Neural Computing and Applications, Pages 16567-16579, 2024.[1] The paper introduces a novel pooling layer called the Common Vector Approach Pooling (CVApool) to improve CNN-based dental disease detection using intraoral X-ray images. The study compares CVApool to traditional average pooling, showcasing CVApool's ability to enhance the accuracy of tooth disease classification across twenty dental conditions organized into seven categories. EfficientNet models, such as EfficientNetB1, B2, B3, and V2S, were utilized, with CVApool achieving a peak accuracy of 86.4%. This research underscores CVApool's effectiveness in increasing CNN model accuracy by overcoming average pooling limitations. However, the dataset's specificity to 2,971 images from a single region could limit broader generalization

Yanlin Chen, Haiyan Du, Zhaoqiang Yun, Shuo Yang, Zhenhui Dai, Liming Zhong, Qianjin Feng, Wei Yang, 2020.[2] This paper presents a method for the automatic segmentation of individual teeth from dental cone-beam computed tomography (CBCT) images. The proposed system utilizes a multi-task 3D fully convolutional network (FCN) combined with a marker-controlled watershed transform (MWT) to segment each tooth. The FCN predicts both tooth regions and surfaces, enhancing accuracy by combining the tooth probability map and surface probability map. The method addresses challenges like blurred tooth boundaries and metal artifacts, achieving high segmentation performance with metrics such as a Dice similarity coefficient of 0.936. The approach offers significant potential for clinical applications, such as digital orthodontic treatment planning.

Yulong Dou, Lanzhuju Mei, Dinggang Shen, Zhiming Cui, 2023.[3] The paper proposes a 3D structure-guided network for aligning teeth in 2D photographs. This method is designed for orthodontics and aims to visualize aligned teeth in patient photographs before treatment, improving communication between orthodontists and patients. The approach uses 3D intra-oral scanning models to guide the alignment in 2D images, employing a diffusion model to project the 3D structure onto the 2D photo space. The network demonstrates superior performance in generating realistic and aesthetically pleasing aligned teeth photos from 2D facial images. This technique could significantly enhance patient engagement and treatment planning within orthodontics.

Tahereh Hassanzadeh, Daryl Essam, Ruhul Sarker, "2D to 3D Evolutionary Deep Convolutional Neural Networks for Medical Image Segmentation," IEEE Transactions on Medical Imaging, Pages 712-721, 2021.[4] This paper presents a method for transitioning from 2D to 3D Convolutional Neural Networks (CNNs) in medical image segmentation using evolutionary computation. A novel approach is proposed where 2D CNNs are evolved first and then converted into 3D networks to handle 3D volume segmentation, saving considerable computational resources. The study compared directly evolved 3D networks to converted 3D networks, demonstrating that the latter can achieve similar or superior accuracy with significantly reduced training time. The methodology was validated using nine different medical segmentation datasets, highlighting the efficiency of 2D-based training for 3D applications. However, limitations in dataset size could impact generalizability.

Tae Jun Jang, Kang Cheol Kim, Hyun Cheol Cho, Jin Keun Seo, "A Fully Automated Method for 3D Individual Tooth Identification and Segmentation in Dental CBCT," IEEE Transactions on Pattern Analysis and Machine Intelligence, Pages 6562-6568, 2022.[5]This study proposes a deep learning-based method for the automated identification and segmentation of individual teeth in 3D cone-beam computed tomography (CBCT) images. A multi-step approach is employed to handle the challenge of segmenting teeth from high-dimensional data with similar intensities between teeth and surrounding bone. The method uses panoramic images to simplify 2D segmentation, followed by 3D segmentation based on loose and tight regions of interest (ROIs). The system achieved an F1-score of 93.35% for identification and a Dice similarity coefficient of 94.79% for segmentation. Despite effective handling of metal artifacts, the dataset's specificity to 97 CBCT images could limit broader applicability

Dogun Kim, Jaeho Choi, Sangyoon Ahn, Eunil Park, 2023.[6]The paper presents a smart home dental care system that integrates deep learning, image sensors, and a mobile controller. This system allows users to capture oral images of their maxillary and mandibular teeth for early detection of dental diseases, such as caries, using a specially designed oral image acquisition device. The system employs convolutional neural networks (CNNs) for tooth disease detection and to determine if professional dental treatment (NPDT) is required. Achieving over 96% accuracy for tooth disease detection and 89% for NPDT, the system enhances home-based dental care by providing effective dental health management and early disease intervention.

Mircea Paul Muresan, Andrei Răzvan Barbura, and Sergiu Nedevschi, "Teeth Detection and Dental Problem Classification in Panoramic X-Ray Images using Deep Learning and Image Processing Techniques," 2020.[7] The study proposes a novel method for automatic teeth detection and classification of dental problems in panoramic X-rays using a deep convolutional neural network (CNN) for semantic segmentation. Images were collected from three clinics, annotated with 14 dental problem categories. The study employed CNN-based segmentation combined with image processing to refine teeth detection and improve accuracy. The system was evaluated with metrics such as intersection over union and F1-score, outperforming other methods but facing challenges with overlapping teeth and image quality.

Shreyansh A. Prajapati, R. Nagaraj, and Suman Mitra, "Classification of Dental Diseases Using CNN and Transfer Learning," 5th International Symposium on Computational and Business Intelligence, Pages 1-10, 2017.[8] The paper presents a CNN-based approach for the classification of dental diseases using a labeled dataset of 251 RVG X-ray images across three classes: dental caries, periapical infection, and periodontitis. The study uses CNN and transfer learning techniques to enhance classification accuracy. Results show that transfer learning with the VGG16 model outperforms a standard CNN with an accuracy of 88.46%. However, the small dataset and complexity of dental X-rays pose challenges in generalizability.

Devesh Saini, Richa Jain, Anita Thakur, "Dental Caries Early Detection using Convolutional Neural Network for Teledentistry," 2021 7th International Conference on Advanced Computing Communication Systems (ICACCS), Pages 1-5, 2021.[9] The paper proposes a CNN-based model for early detection of dental caries using digital images, suitable for teledentistry applications. Various CNN models including VGG16, VGG19, InceptionV3, and ResNet50 were tested, with InceptionV3 achieving the highest accuracy of 99.89%. The study highlights the importance of early caries detection to prevent severe dental issues and leverages soft computing techniques to reduce diagnostic time. However, the dataset of 500 images limits the generalization of the model.

Zhiyang Zheng, Hao Yan, Frank C. Setzer, Katherine J. Shi, Mel Mupparapu, Jing Li ,2020.[10] The paper "Anatomically Constrained Deep Learning for Automating Dental CBCT Segmentation and Lesion Detection" introduces a novel deep learning method using an anatomically constrained Dense U-Net. This approach integrates oral-anatomical knowledge into a data-driven neural network to address challenges in segmenting dental cone beam computed tomography (CBCT) images. CBCT data are complex, with varying tissues and materials that are hard to segment accurately with existing methods.

Raphael Patcas,Michael M.Bornsteinaims,2022.[11] The paper "Artificial intelligence in medico-dental diagnostics of the face: a narrative review of opportunities and challenges" to share the current developments of artificial intelligence (AI) solutions in the field of medico-dental diagnostics of the face. The primary focus of this review is to present the applicability of artificial neural networks (ANN) to interpret medical images, together with the associated opportunities, obstacles, and ethico-legal concerns.

Gautam Chitnis,Vidhi Bhanushali,Aayush Ranade,2020.[12] The paper "A Review of Machine Learning Methodologies for Dental Disease Detection" dental diseases have become commonplace in today‘s fast paced world. Currently, most medical practitioners rely on manual analysis of a patient's oral cavity for initial diagnosis. Later, they rely on manual analysis of radiographs or x-rays for advanced diagnosis. To reduce this effort, systems are proposed for disease detection techniques working with radiographs or x-rays, which are only accessible to dental practitioners. Other techniques that work on raw, visible light based images of oral cavity have been trained on miniscule datasets with a narrow list of diseases that can be detected. There have been efforts in recent times to repurpose the general use machine learning algorithms such as CNNs for the particular task of disease detection and classification in medical imaging.

S. Sivagami, P.Chitra, G. SriRam Kailash, S.R.Muralidharan,2020.[13]This paper"UNet Architecture Based Dental Panoramic Image Segmentation" proposes an UNet architecture that uses convolutional neural networks to achieve accurate segmentation of Dental panoramic x-ray images. In dentistry, Radiographic images help medical experts to identify and diagnose the disease in an accurate manner X-rays, Computed Tomography (CT), Magnetic resonance imaging (MRI) are some of the radiographic images. Generally, X-ray images are complex in nature. The presence of noise results in lack of reliable separation between the various parts of teeth. This makes the segmentation process very difficult. Dental image segmentation helps the dentist to detect the impacted teeth, find the accurate position for the placement of dental implants and determine the orientation of teeth structure. UNet architecture model is a recent approach used for medical image segmentation.

HaihuaZhu, ZhengCao, LuyaLian1,GuanchenYe,2022.[14]This paper propose"CariesNet: a deep learning approach for segmentation of multi-stage caries lesion from oral panoramic X-ray image" This paper proposes dental caries has been a common health issue throughout the world, which can even lead to dental pulp and root apical inflammation eventually. Timely and effective treatment of dental caries is vital for patients to reduce pain. Traditional caries disease diagnosis methods like naked-eye detection and panoramic radiograph examinations rely on experienced doctors, which may cause misdiagnosis and high time-consuming. To this end, we propose a novel deep learning architecture called CariesNet to delineate different caries degrees from panoramic radiographs. We firstly collect a high-quality panoramic radiograph dataset with 3127 well-delineated caries lesions, including shallow caries, moderate caries, and deep caries. Then we construct CariesNet as a U-shape network with the additional full-scale axial attention module to segment these three caries types from the oral panoramic images.

AsmaulHosna, Ethel Merry, Jigmey-Gyalmo, Zulfikar Alom,2022.[15] This paper propose "Transfer learning: a friendly introduction" This paper contributes to the domain and scope of TL, citing situational use based on their periods and a few of its applications. The paper provides an in-depth focus on the techniques; Inductive TL, Transductive TL, Unsupervised TL, which consists of sample selection, and domain adaptation, followed by contributions and future directions.

Sr. No	Title	Author(s)	Year	Methodology	Drawback
1	Classification of Dental Cavities from X-ray Images using Deep CNN Algorithm	Shreyansh A. Prajapati, R. Nagaraj and Suman Mitra	2020	Segmentation Technique, Feature Extraction, Deep CNN Classification	Limited performance in complex cases like overlapping teeth. May not generalize well for other dental diseases beyond cavities
2	Teeth Detection and Dental Problem Classification in Panoramic X-Ray Images using Deep Learning and Image Processing Techniques	Mircea Paul Muresan, Andrei Rzvan Barbura, Sergiu Nedevschi	2020	ERFNet for semantic segmentation, image processing, tooth detection, data collection	Struggles with overlapping teeth. Computationally expensive, needs optimization
3	Dental Caries Early Detection using Convolutional Neural Network for Teledentistry	Devesh Saini, Richa Jain, Anita Thakur	2021	CNN models (Vgg16, Vgg19, InceptionV3, ResNet50) to detect dental caries from 500 images	Preprocessing, Vgg models were slow and resource-heavy. Limited dataset size (500 images) affects generalizability
4	CVApool: Using Null-Space of CNN Weights for Tooth Disease Classification	Zuhal Can, Sahin Isik, Yildiray Anagun	2024	Pre-trained CNN models (EfficientNetB1, B2, B3, V2S) with CVApool	Risk of overfitting in complex models
5	2D to 3D Evolutionary Deep Convolutional Neural Networks for Medical Image Segmentation	Tahereh Hassanzadeh, Daryl Essam, Ruhul Sarker	2020	U-Net architecture, converts optimized 2D networks to 3D	High computational cost, limited generalization, time-consuming
6	A Fully Automated Method for 3D Individual Tooth Identification and Segmentation in Dental CBCT	Tae Jun Jang, Kang Cheol Kim, Hyun Cheol Cho, Jin Keun Seo	2022	Multi-step deep learning model, teeth detection and segmentation, 3D ROIs	Metal artifacts impact segmentation accuracy. Tight ROIs may cut off parts of teeth
7	3D Structure-Guided Network for Tooth Alignment in 2D Photographs	Yulong Dou, Lanzhuju Mei, Dinggang Shen, Zhiming Cui	2023	Segmentation using U-net, alignment using Diffusion, generation using Gen-Mod	Does not account for occlusal relationships. No 3D reconstruction from 2D images, limiting detailed orthodontic applications
8	A Smart Home Dental Care System: Integration of Deep Learning, Image Sensors, and Mobile Controller	Dogun Kim, Jaeho Choi, Sangyoon Ahn, Eunil Park	2021	RetinaNet detects teeth regions, ResNeXt classifies tooth diseases	Small dataset. Individual user traits not considered in the model

Sr. No	Title	Author(s)	Year	Methodology	Drawback
9	Automatic Segmentation of Individual Tooth in Dental CBCT Images from Tooth Surface Map by a Multi-Task FCN	Yanlin Chen, Haiyan Du, Zhaoqiang Yun	2020	Two-Branch Fully Convolutional Network (FCN) predicts tooth region and surface probability maps	Limited dataset (25 CBCT images) affects generalizability
10	Anatomically Constrained Deep Learning for Automating Dental CBCT Segmentation and Lesion Detection	Zhiyang Zheng, Katherine J. Shi, Mel Mupparapu, Jing Li	2020	Dense U-Net, CBCT segmentation, lesion detection	Small dataset, limited anatomical knowledge
11	Artificial intelligence in medico-dental diagnostics of the face: a narrative review of opportunities and challenges	Raphael Patcas,Michael M.Bornstein	2022	Focus on ANN, using deep learning for medical image analysis	Need for large, diverse datasets, privacy concerns, and a lack of standardized evaluation criteria
12	A Review of Machine Learning Methodologies for Dental Disease Detection	Gautam Chitnis,Vidhi Bhanushali,Aayush Ranade	2020	CNN and Mask R-CNN for dental disease detection. Transfer learning and fine-tuning	Small datasets limit model performance. Accuracy below clinical standards
13	UNetArchitecture Based Dental Panoramic Image Segmentation	S. Sivagami, P. Chitra, G. Sri Ram Kailash, S.R.Muralidharan	2020	Combines contraction and expansion paths with skip connections.	Focuses only on panoramic X-rays
14	CariesNet: a deep learning approach for segmentation of multi-stage caries lesion from oral panoramic X-ray image	HaihuaZhu, Zheng Cao, LuyaLian1, GuanchenYe	2022	CariesNet(U-shape network) with full-scale axial attention (FSAA) for caries segmentation. FSAA improves boundary detection for caries lesions.	Difficulty in accurately segmenting moderate caries due to blurred boundaries. Time consuming data collection and annotation
15	Transfer learning: a friendly introduction	AsmaulHosna, Ethel Merry, Jigmey-Gyalmo, Zulfikar Alom	2022	Sample selection, domain adaptation, and kernel mean matching. It reuses knowledge from a source task to improve a target task.	Negative transfer can harm performance if tasks/domains are unrelated to Sample selection bias may lead to inaccurate models.

Table 2.1: Comparative Analysis of Literature Survey

Chapter 3

Project Design

3.1 Existing System

The existing healthcare system in hospitals and clinics with a high patient load and a limited number of doctors faces several challenges. Currently, the diagnosis and treatment process relies heavily on manual analysis, where doctors examine symptoms, review medical history, and interpret test reports. This approach is time-consuming, often leading to long wait times and delayed treatment. Additionally, accessibility remains a concern, as patients in remote areas or those with mobility issues struggle to receive timely medical attention.

The diagnosis process also lacks consistency, as different doctors may interpret symptoms and test results differently, leading to variations in treatment recommendations. Furthermore, patients must manually provide their test reports, which doctors analyze without AI assistance, making the process slower and increasing the chances of human error.

Another major drawback of the existing system is the lack of personalized recommendations, as current healthcare platforms do not utilize AI-driven insights to suggest treatments based on a patient's medical history and symptom patterns. Moreover, doctor-patient interaction is often limited to hospital visits, making follow-ups challenging and reducing the continuity of care.

Due to these inefficiencies, there is a growing need for an AI-driven healthcare assistant that automates preliminary diagnoses, analyzes medical data effectively, and provides intelligent treatment recommendations to support doctors in decision-making.

3.2 Proposed System

System Architecture is crucial for visualizing the overall structure of the system, showing how different components interact with each other. It provides a high-level view that helps in understanding the dependencies and flow within the system.This diagram represents a proposed system architecture for a dental care platform that integrates AI, user interaction, and backend processing. The architecture is divided into four main layers.

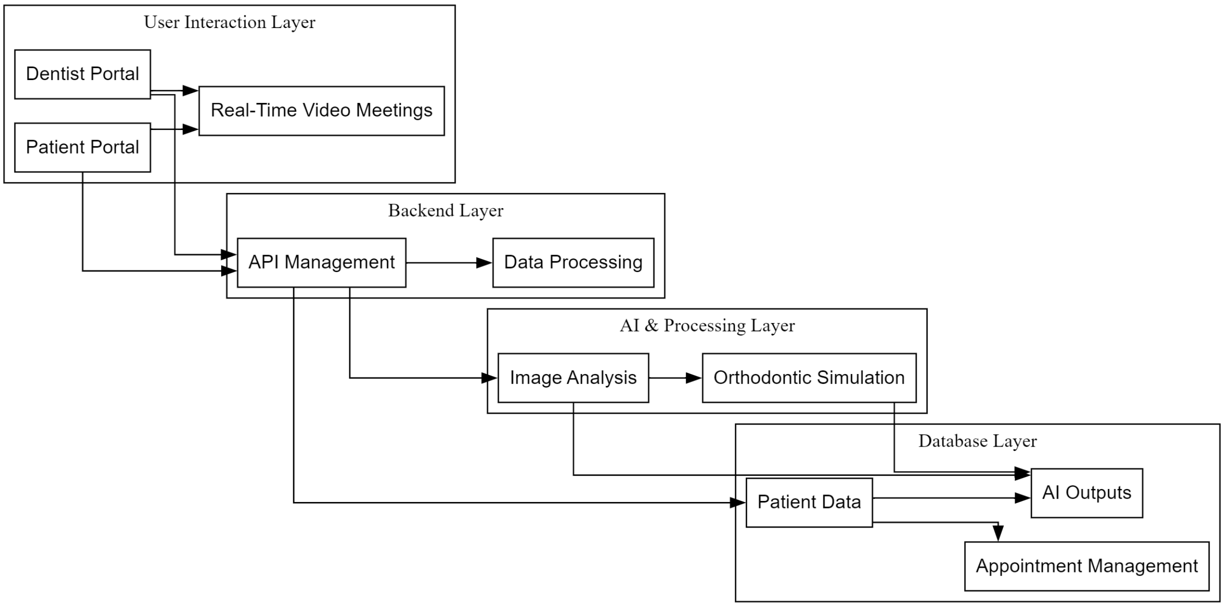

Figure 3.1: Proposed System Architecture of Smart Dent-AI

The **User Interaction Layer** provides portals for both patients and dentists. Through these, patients can upload dental images and schedule appointments, while dentists can review reports. Both users can engage in real-time video consultations for remote interactions.

In the **Backend Layer**, API Management handles communication between the front end and the system's core. Data Processing ensures that all incoming data is validated and organized properly before it moves to the next step.

The **AI Processing Layer** performs Image Analysis on the uploaded dental images, generating diagnostic insights. It also offers Orthodontic Simulations to suggest possible treatment options.

Lastly, the **Database Layer** securely stores patient data, including AI-generated diagnostic results, and manages Appointment Scheduling to organize follow-up treatments. This architecture enables seamless interaction between patients and dentists, supported by AI insights and robust data management.

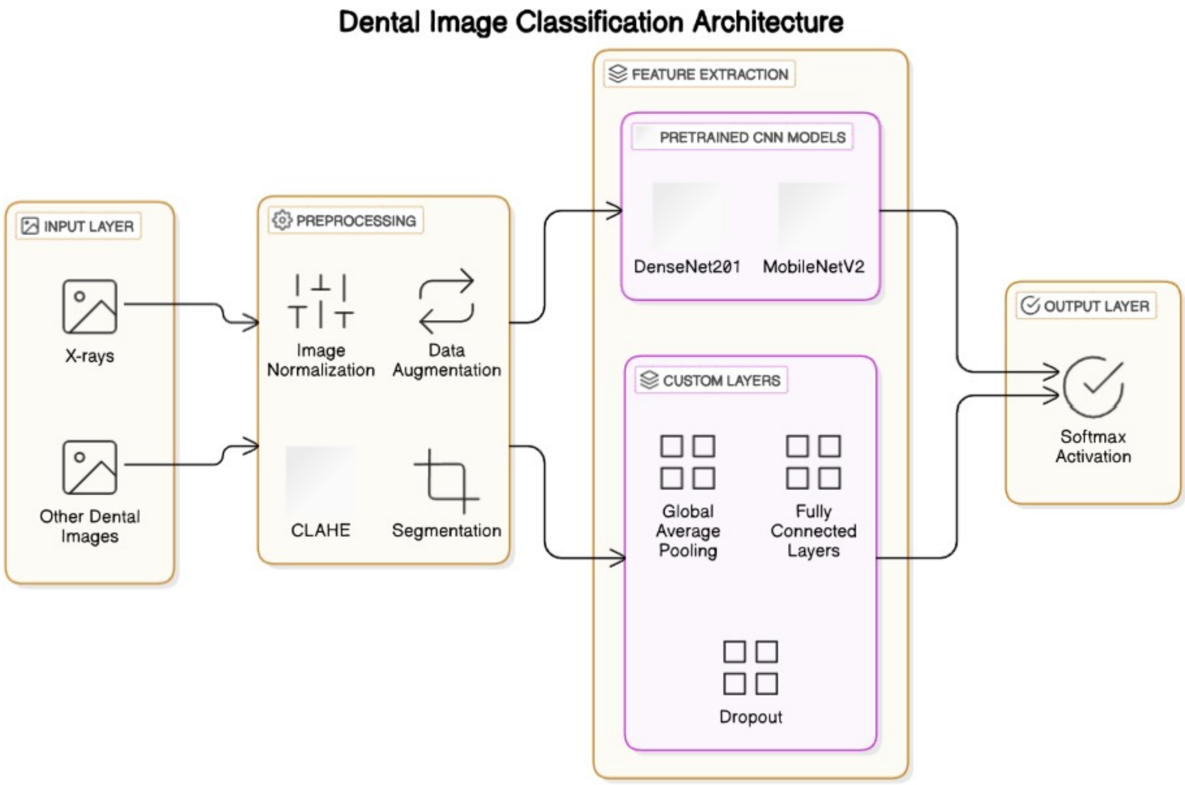

Figure 3.2: Dental Image Classification Workflow

The figure 3.2 represents a dental image classification workflow. It starts with uploading X-ray or oral images, which are then preprocessed through steps like image normalization, data augmentation, and image processing techniques such as **CLAHE** (to enhance contrast) and segmentation (to focus on relevant areas). The processed images are passed into convolutional neural networks (CNNs) such as **DenseNet201** and **MobileNetV2**, both pretrained on **ImageNet** for improved feature extraction. Custom layers, including global average pooling, dense layers, and dropout, help refine the learning process and reduce overfitting. Finally, a softmax output layer classifies the images by providing the probability of each class.

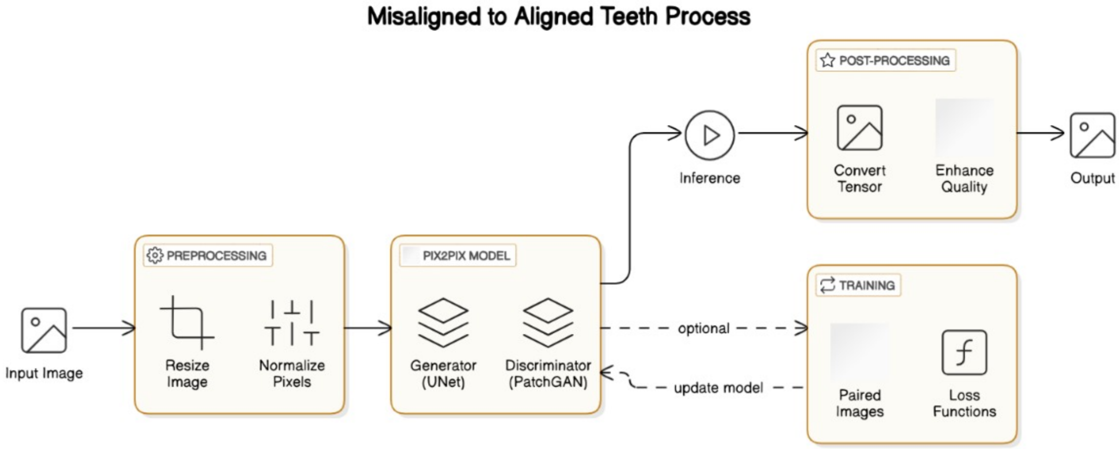

Figure 3.3: Orthodontic Treatment Simulation Workflow

The figure 3.3 represents the process of transforming misaligned teeth images into aligned ones using deep learning begins with Preprocessing. This step standardizes input images by resizing them to maintain uniform dimensions and normalizing pixel values for stable model convergence and improved computational efficiency.Next, the Pix2Pix Model, a conditional GAN, performs image-to-image translation. The Generator, based on the UNet architecture, transforms misaligned teeth images while preserving structural details through skip connections. The Discriminator, utilizing PatchGAN, evaluates the generated images by analyzing small patches to ensure realistic textures and edges.During Inference, the trained model is applied to new images, generating aligned teeth outputs in real time. The process leverages learned weights and iterative refinements to improve alignment accuracy and overall quality.To enhance the final result, Post-Processing converts the model output into a visual image format and applies sharpening, noise reduction, and contrast adjustments, refining the image for clinical or aesthetic use.The final Output Image represents the corrected version of misaligned teeth, demonstrating the effectiveness of deep learning-based image translation in dental applications.

3.2.1 Critical Components of System Architecture

The SmartDent-AI system architecture is composed of multiple critical components, ensuring seamless AI-powered dental healthcare services. At the forefront is the User Interface (Frontend Layer), developed using React.js, HTML, CSS, and JavaScript, providing an intuitive dashboard for patients and dentists. This layer enables users to upload images, book appointments, access reports, and conduct real-time video consultations through the Zego Cloud API. Supporting the frontend is the Backend Layer, powered by Node.js and Flask, which manages user authentication, appointment scheduling, and API requests. It acts as a bridge between the user interface, the machine learning models, and the database, ensuring smooth data exchange through REST APIs.

The Machine Learning and AI Processing Layer forms the core intelligence of the system, utilizing TensorFlow, Keras, and OpenCV to handle automated diagnostics. This includes the Teeth Alignment Prediction module, which leverages a Pix2Pix cGAN for image-to-image translation, transforming misaligned teeth images into properly aligned ones. Additionally, X-ray Disease Detection is powered by DenseNet201 and MobileNetV2 for accurate classification, while the Oral Disease Detection module extends CNN-based analysis to detect external dental conditions. Post-processing techniques such as noise reduction and contrast enhancement further refine the generated outputs for clinical use.

All patient records, dental images, diagnosis history, and appointment details are securely managed by the Database and Storage Layer, which integrates MySQL and Firebase. This ensures real-time updates, structured data retrieval, and authentication services, facilitating a seamless experience for both patients and dental professionals. The Cloud Services and Integration Layer enhances accessibility by enabling secure cloud storage of medical records and images through Firebase, while the Zego Cloud API supports encrypted real-time video consultations, ensuring privacy and confidentiality.

Security remains a top priority in the Security and Privacy Layer, which implements end-to-end encryption, HIPAA/GDPR compliance, and role-based access control (RBAC) to safeguard sensitive patient data. AI model inference and data transfer are also secured through encryption mechanisms. To further enhance system efficiency, External API Integrations such as Google Calendar API allow appointment scheduling synchronization, while an automated notification system sends reminders via email or push notifications. If required, a payment gateway can also be integrated to facilitate online consultation payments.

Together, these interconnected components create a scalable, AI-driven dental healthcare ecosystem, providing automated diagnostics, efficient patient management, and seamless remote consultations while maintaining security and compliance.

3.3 System Diagrams

3.3.1 UML Diagram

The Smart Dental System is an AI-powered healthcare solution designed to assist in diagnosing dental conditions and managing patient consultations. UML diagrams help in structuring the system by visually representing interactions, processes, and data flow between different components.

The system enables patients to upload dental images, which are processed using AI to predict possible diseases. If a disease is detected, the information is stored and reviewed by a dentist. Based on the diagnosis, patients can either book an appointment or opt for a virtual consultation. The system ensures seamless data management by integrating an AI model, database, and appointment module to streamline the workflow.

Automation within the system improves accuracy and efficiency in dental diagnostics, reducing the dependency on manual examination. The use of AI for early detection enhances patient care, while the appointment module ensures timely consultations. The structured approach of UML diagrams supports clear system development, aiding in scalability.

3.3.2 Activity Diagram

This Activity Diagram represents the Smart Dental System Process Flow, illustrating the sequential steps in diagnosing dental issues using AI and scheduling further consultations if needed.

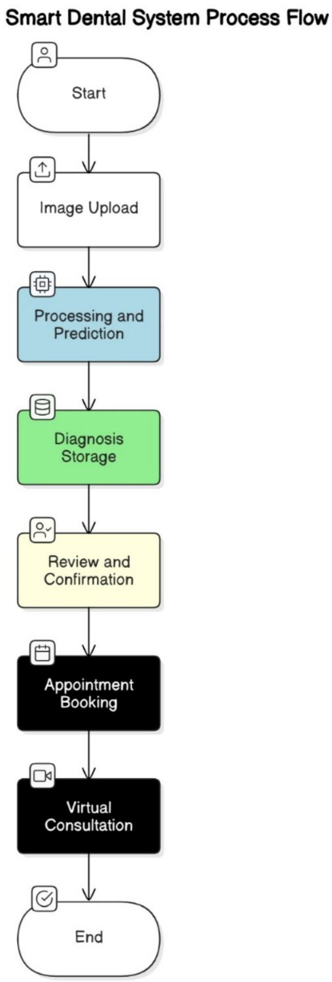

Figure 3.4: Activity Diagram of Smart Dent-AI

The process begins with the Start node, where a Patient uploads a dental image to the system. The image then undergoes Processing and Prediction, where an AI model analyzes the image for possible dental diseases. The diagnosis is then stored in the system under Diagnosis Storage for further reference.

Following this, the Review and Confirmation step takes place, where a Dentist reviews the diagnosis to confirm the AI's prediction. If required, the system proceeds to Appointment Booking, where a patient can schedule an in-person visit. Additionally, if a virtual consultation is needed, the system facilitates an online appointment for further discussion. Finally, the process concludes at the End node, marking the completion of the diagnostic and consultation workflow.

This diagram effectively visualizes the flow of the Smart Dental System, ensuring a smooth and structured process for AI-based dental analysis and consultation management.

3.3.3 Data Flow Diagram

Data Flow Diagrams are essential in modeling the flow of data through the system. They help break down the system into smaller, understandable components by showing how inputs are processed and converted into outputs.

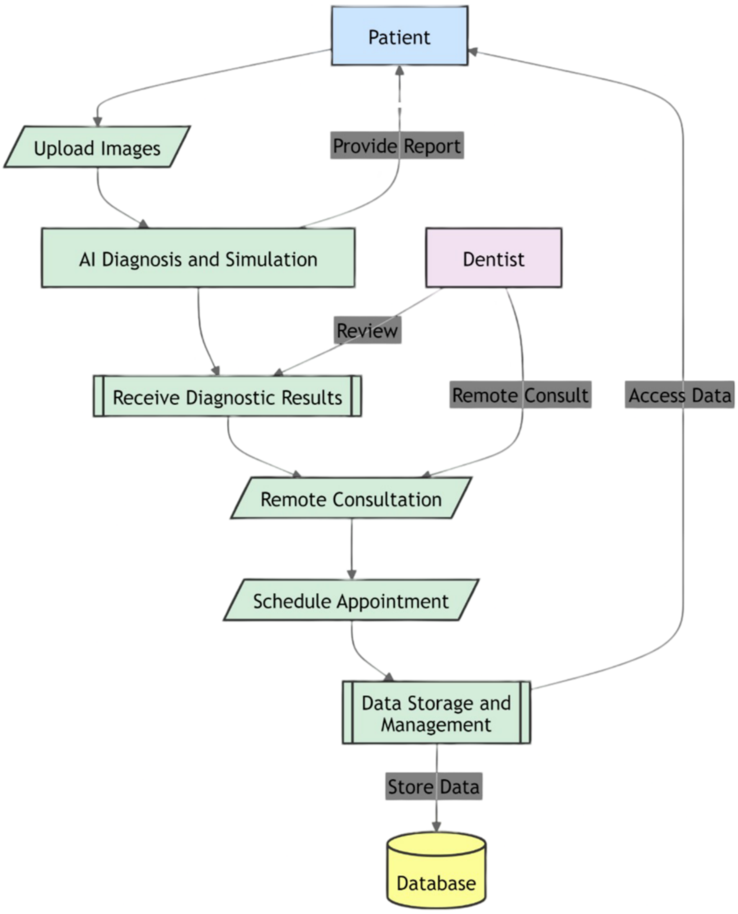

Figure 3.5: Data Flow Diagram (DFD) of Smart Dent-AI

This Data Flow Diagram (DFD) shows how data moves within an AI-driven dental care system. The process begins with the patient uploading dental images, which are analyzed by the AI. The results are sent to both the patient and the dentist, who reviews them and may engage in a remote consultation with the patient to discuss the findings. If needed, the patient can also schedule a follow-up appointment for further treatment.

All data, including diagnostic results and consultation details, is managed and stored in the system's database for future access. This ensures secure and efficient data handling while allowing seamless interaction between the patient, the dentist, and the AI system, combining remote care with intelligent diagnostics.

3.3.4 Use Case Diagram

Use Case Diagrams represent the interaction between users (actors) and the system. They help identify the key functionalities of the system from the user's perspective. For our project, the Use Case Diagram shows: - Major actions users can perform - Interaction points between the system and external users or subsystems.

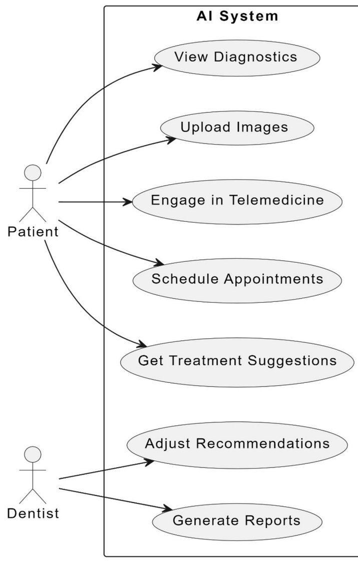

Figure 3.6: Use Case Diagram of Smart Dent-AI

This use case diagram shows how an AI-powered system facilitates interactions between **patients** and **dentists**. The system enables patients to take an active role in their dental care, while also allowing dentists to provide expert oversight and guidance.

For patients, the system offers several key functions. Patients can upload dental images, such as X-rays, which the AI analyzes to provide diagnostic information. They can then view these diagnostics, helping them understand their oral health. The system also supports telemedicine, allowing patients to consult with a dentist remotely. Additionally, patients can schedule appointments for further consultations or treatments, and receive treatment suggestions from the AI based on the diagnostic results.

Overall, the system enhances efficiency by combining AI-driven diagnostics and treatment planning with the expertise of dentists, while making dental care more accessible for patients This use case diagram underscores the collaborative nature of the system, bridging the gap between patients and dental professionals. By empowering patients to engage actively in their dental health journey, the platform fosters a sense of ownership and awareness. At the same time, it enables dentists to leverage advanced AI analytics to make informed decisions, ultimately improving treatment outcomes. The seamless integration of technology into dental care not only streamlines processes but also enhances the overall patient experience, making dental health management more proactive and accessible than ever before.

3.3.5 Sequence Diagram

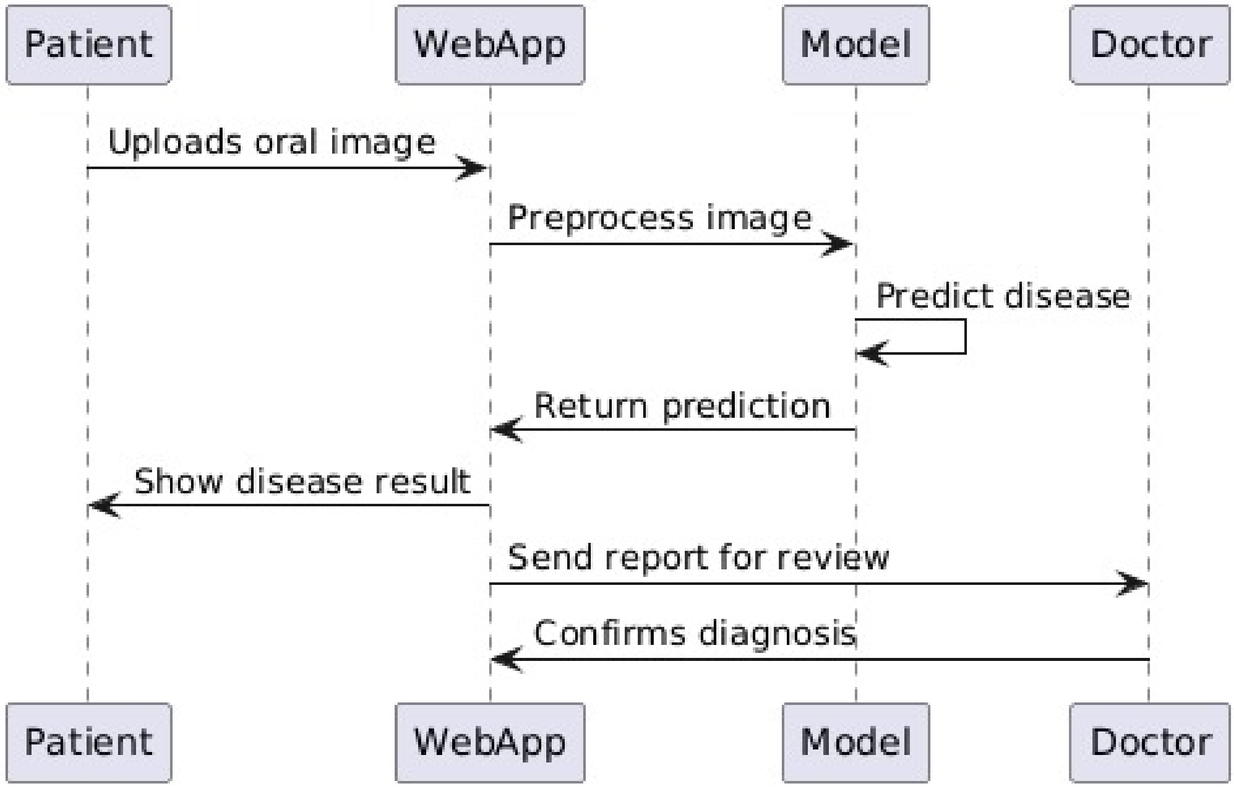

Figure 3.7: Sequence Diagram of Smart Dent-AI

The sequence diagram for SmartDent-AI illustrates the interaction between different components involved in the dental disease prediction system. The process begins with the patient, who uploads an oral image, such as a dental X-ray, through the web application. This image is then preprocessed by the web app to ensure it is suitable for analysis, which may include resizing, filtering, or normalization techniques.

Once preprocessing is complete, the web app forwards the image to the AI model, which is trained to detect and predict possible dental diseases. The model processes the image using deep learning techniques and generates a prediction based on its trained dataset. This prediction is then sent back to the web app, where it is displayed to the patient, giving them an initial insight into their dental health.

To ensure accuracy, the system includes a doctor review process. The web app forwards the AI-generated report to a dentist, who carefully examines the prediction. The doctor then confirms or modifies the diagnosis based on their expertise. Finally, the validated diagnosis is sent back to the patient through the web app, ensuring a balance between AI automation and human expertise.

This sequence diagram effectively highlights the hybrid nature of SmartDent-AI, where AI-powered automation is complemented by human verification to enhance reliability and accuracy. The system streamlines the diagnostic process, making dental health assessments more efficient, accessible, and accurate for patients.

Chapter 4

Project Implementation

In this section, we will provide implementation snippets of the project to give you a better understanding of how the code works. These snippets will highlight some of the methods utilized to obtain the required outcomes while showcasing the project's main functionality. These snippets represent the flow of actions that the users will need to follow to access the system.

4.1 Code Snippets

4.1.1 ResidualBlock Class

```
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.block = nn.Sequential(
            nn.Conv2d(channels, channels, 3, padding=1),
            nn.InstanceNorm2d(channels),
            nn.ReLU(inplace=True),
            nn.Conv2d(channels, channels, 3, padding=1),
            nn.InstanceNorm2d(channels)
        )
    def forward(self, x):
        return x + self.block(x)
```

Figure 4.1: ResidualBlock Class (Residual Learning for Generator)

This code snippets as class defines a Residual Block, a fundamental component of deep networks that helps prevent the vanishing gradient problem. The block consists of two 3x3 convolutional layers, each followed by Instance Normalization and a ReLU activation function. The output of this block is the sum of the input and the transformed features, helping the model learn identity mappings efficiently, which speeds up training and improves performance.

4.1.2 Generator Network

```
class Generator(nn.Module):
    def _init_(self):
        super(Generator, self)._init_()

        self.init_block = nn.Sequential(
            nn.Conv2d(3, 64, 7, padding=3, padding_mode='reflect'),
            nn.InstanceNorm2d(64),
            nn.ReLU(inplace=True)
        )

        self.down1 = nn.Sequential(
            nn.Conv2d(64, 128, 3, stride=2, padding=1),
            nn.InstanceNorm2d(128),
            nn.ReLU(inplace=True)
        )
        self.down2 = nn.Sequential(
            nn.Conv2d(128, 256, 3, stride=2, padding=1),
            nn.InstanceNorm2d(256),
            nn.ReLU(inplace=True)
        )

        self.res_blocks = nn.Sequential(
            *[ResidualBlock(256) for _ in range(6)]
        )
```

Figure 4.2: Generator Network 1 (Image-to-Image Translation Model)

```
        self.up1 = nn.Sequential(
            nn.ConvTranspose2d(256, 128, 3, stride=2, padding=1, output_padding=1),
            nn.InstanceNorm2d(128),
            nn.ReLU(inplace=True)
        )
        self.up2 = nn.Sequential(
            nn.ConvTranspose2d(128, 64, 3, stride=2, padding=1, output_padding=1),
            nn.InstanceNorm2d(64),
            nn.ReLU(inplace=True)
        )

        self.output_block = nn.Sequential(
            nn.Conv2d(64, 3, 7, padding=3, padding_mode='reflect'),
            nn.Tanh()
        )

    def forward(self, x):
        x = self.init_block(x)
        x = self.down1(x)
        x = self.down2(x)
        x = self.res_blocks(x)
        x = self.up1(x)
        x = self.up2(x)
        x = self.output_block(x)
        return x
```

Figure 4.3: Generator Network 2 (Image-to-Image Translation Model)

This code snippets is Generator model is designed to transform an input image into a generated output, commonly used in image-to-image translation tasks such as style transfer and medical image enhancement. It begins with an initial block that converts an RGB image with three channels into a 64-channel feature representation using a 7x7 convolution. Following this, downsampling layers reduce the image size while increasing the feature depth to 256 channels, allowing for deeper feature extraction. The core of the model consists of six residual blocks, which facilitate deeper learning while preserving important information. To restore the image to its original size, upsampling layers utilize transposed convolutions. Finally, the output layer applies a Tanh activation function, ensuring pixel values are normalized between -1 and 1, making them suitable for image-based applications.

4.1.3 Discriminator Network

```
class Discriminator(nn.Module):
    def _init_(self):
        super(Discriminator, self)._init_()

        def discriminator_block(in_filters, out_filters, normalize=True, stride=2):
            layers = [nn.Conv2d(in_filters, out_filters, 4, stride=stride, padding=1)]
            if normalize:
                layers.append(nn.InstanceNorm2d(out_filters))
            layers.append(nn.LeakyReLU(0.2, inplace=True))
            return layers

        self.model = nn.Sequential(
            *discriminator_block(3, 64, normalize=False),
            *discriminator_block(64, 128),
            *discriminator_block(128, 256),
            *discriminator_block(256, 512),
            nn.Conv2d(512, 1, 4, stride=1, padding=1)
        )

    def forward(self, x):
        return self.model(x)  # Returns a tensor of shape (batch_size, 1, 15, 15)
```

Figure 4.4: Discriminator Network (PatchGAN-based Discriminator)

This code snippets is Discriminator is a PatchGAN classifier designed to assess whether an image is real or fake. It utilizes convolutional layers with 4x4 convolutions to extract features at different scales, enabling effective analysis of image details. Instance normalization is applied to stabilize training by normalizing feature maps. To prevent vanishing gradients and improve learning, the model incorporates Leaky ReLU activation. Instead of providing a single classification output, the final layer generates a 15x15 probability map, which evaluates real vs. fake patches across the image, enhancing fine-grained detection and improving the model's ability to differentiate subtle details.

4.1.4 MobileNetV2 for Oral Disease Classification

```
import torch
import torch.nn as nn
import torchvision.models as models

class OralDiseaseClassifier(nn.Module):
    def _init_(self, num_classes):
        super(OralDiseaseClassifier, self)._init_()
        self.backbone =
models.mobilenet_v2(weights=models.MobileNet_V2_Weights.DEFAULT)
        self.backbone.classifier = nn.Sequential(
            nn.Linear(self.backbone.last_channel, 512),
            nn.ReLU(),
            nn.Dropout(0.4),
            nn.Linear(512, num_classes)
        )

    def forward(self, x):
        return self.backbone(x)
```

18:46

Figure 4.5: MobileNetV2 for Oral Disease Classification

This code snippets defines an oral disease classification model using MobileNetV2, a lightweight and efficient CNN. The pretrained MobileNetV2 backbone extracts image features, while a custom classifier head refines them. The classifier consists of a fully connected layer (512 neurons) with ReLU activation, a Dropout (0.4) layer to prevent overfitting, and a final output layer for disease classification. The model leverages transfer learning, ensuring improved accuracy with fewer training resources, making it ideal for medical image analysis.

4.1.5 Densenet201 for Xray Classification

```
# Define the Model
class DentalRadiographyModel(torch.nn.Module):
    def _init_(self, num_classes):
        super(DentalRadiographyModel, self)._init_()
        # Load a pretrained DenseNet-201 model
        self.backbone = timm.create_model("densenet201", pretrained=True,
num_classes=0)
        self.fc = torch.nn.Linear(self.backbone.num_features, num_classes)  # Custom
classifier

    def forward(self, x):
        x = self.backbone(x)  # Feature extraction
        x = self.fc(x)  # Classification layer
        return x
```

Figure 4.6: Densenet201 for Xray Classification

This code snippets is model uses DenseNet-201, a deep convolutional neural network known for its dense connections, which improve feature propagation and gradient flow. It is initialized using timm.create-model(”densenet201”, pretrained=True, num-classes=0), loading a pretrained DenseNet-201 without the classification head. A fully connected layer is then added to map the extracted features to the required number of classes. During the forward pass, the input image is processed through the DenseNet-201 backbone to extract meaningful representations, which are then passed through the custom classifier for final predictions. This architecture enhances feature reuse and is well-suited for dental radiography classification tasks.

4.2 Steps to access the System

In this section, we will provide proper steps to access of the project to give you a better walk through how the system operates. These steps will highlight some of the methods utilized to obtain the required outcomes while showcasing the project's main functionality. These section represent the flow of actions that will need to follow to access the system.

4.2.1 User Authentication and Verification

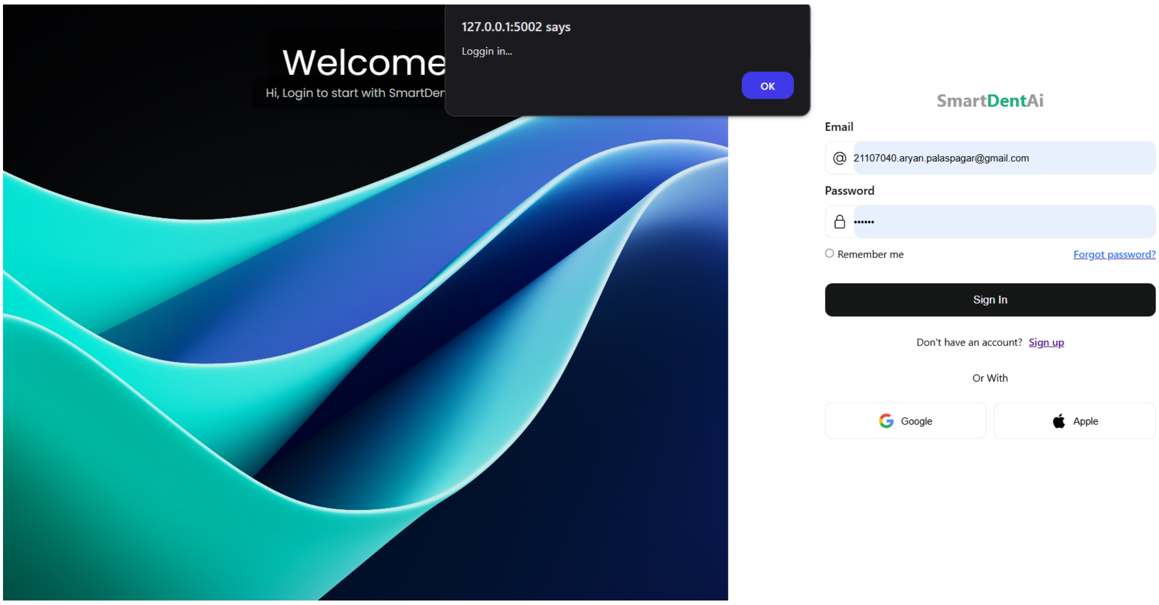

Figure 4.7: Login Page of Smart Dent-AI

The Smart Dental System begins with User Authentication and Verification to ensure secure access. Users must enter their registered credentials, such as email and password. For new users, the system provides a registration option, requiring details like name, contact number, and email. A verification process, such as OTP verification or email confirmation, ensures authenticity. After successful authentication, users are directed to their respective dashboards based on their roles, granting access to relevant features and functionalities.

4.2.2 Dashboard

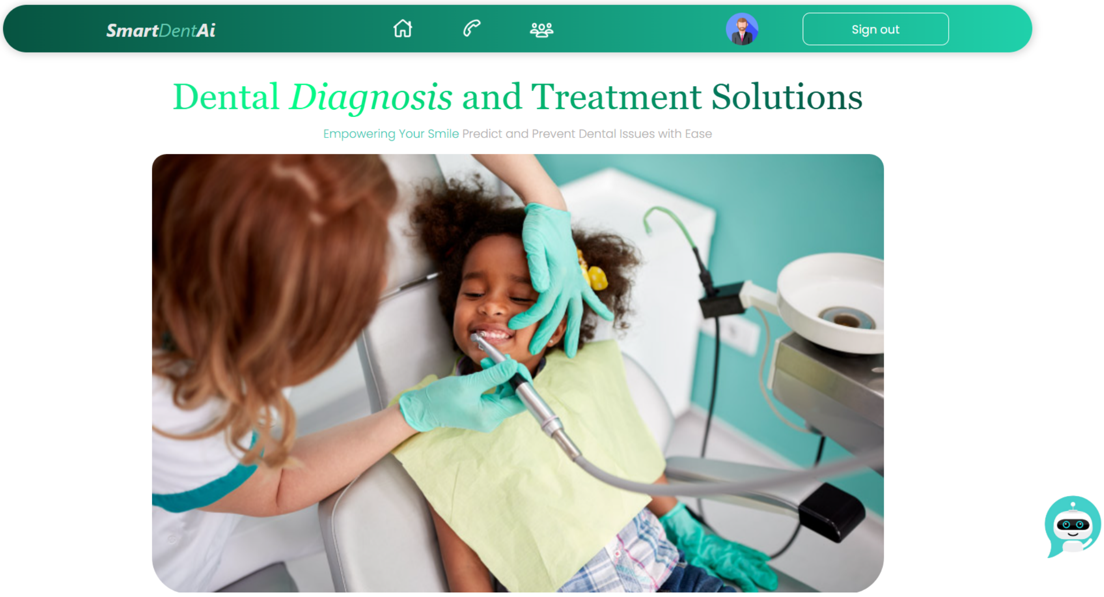

Figure 4.8: Dashboard of Smart Dent-AI

Once the user successfully logs into the SmartDent-AI system, they are directed to the Dashboard, which serves as the central hub for accessing various features and modules. The dashboard provides an intuitive and user-friendly interface where users can seamlessly navigate through different functionalities such as appointment scheduling, patient records, AI-driven diagnosis, and treatment recommendations.
The dashboard is designed to offer personalized insights based on user roles. Patients can view their upcoming appointments, dental history, and AI-based dental health insights, while dentists can access patient records, treatment plans, and diagnostic tools. Additionally, administrators can manage system configurations, users, and security settings. The dashboard enhances user experience with real-time notifications, appointment reminders, and interactive tools for efficient dental care management.

4.2.3 The Dental Diagnosis and Treatment Solution

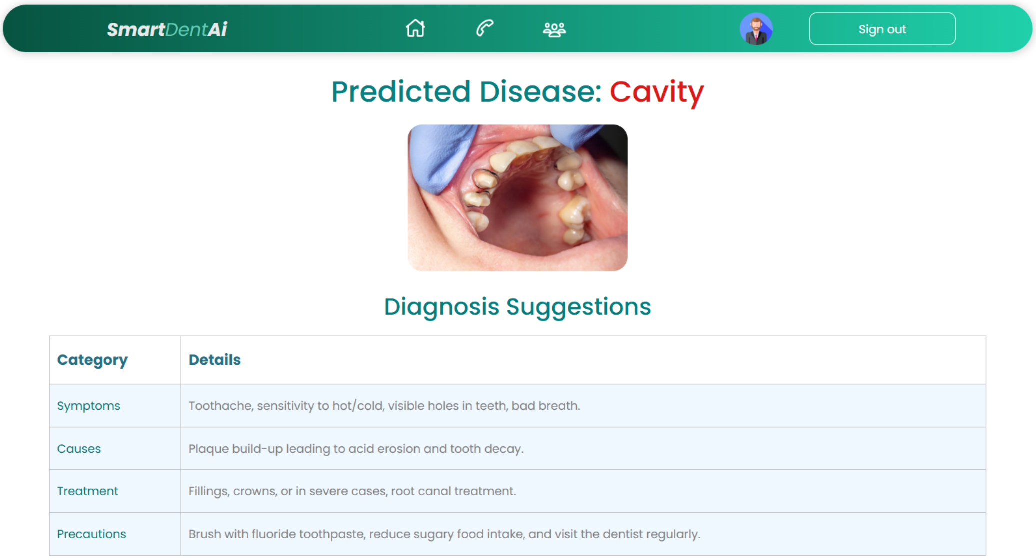

Figure 4.9: Dental Diagnosis and Treatment Solutions of Smart Dent-AI

The Dental Diagnosis and Treatment Solution page enables users to upload X-ray images and oral photographs for AI-based dental analysis. Once the image is uploaded, the system processes it using advanced machine learning algorithms to predict potential dental conditions such as cavities, gum disease, or other oral health concerns.
After diagnosis, the system provides detailed insights into the predicted condition, including its symptoms, causes, treatment options, and preventive measures. Users receive personalized treatment recommendations, which may include dental procedures, medication, or lifestyle changes to improve oral health. This feature helps patients and dentists make informed decisions and ensures early detection of dental issues.

4.2.4 Misaligned to Aligned Teeth

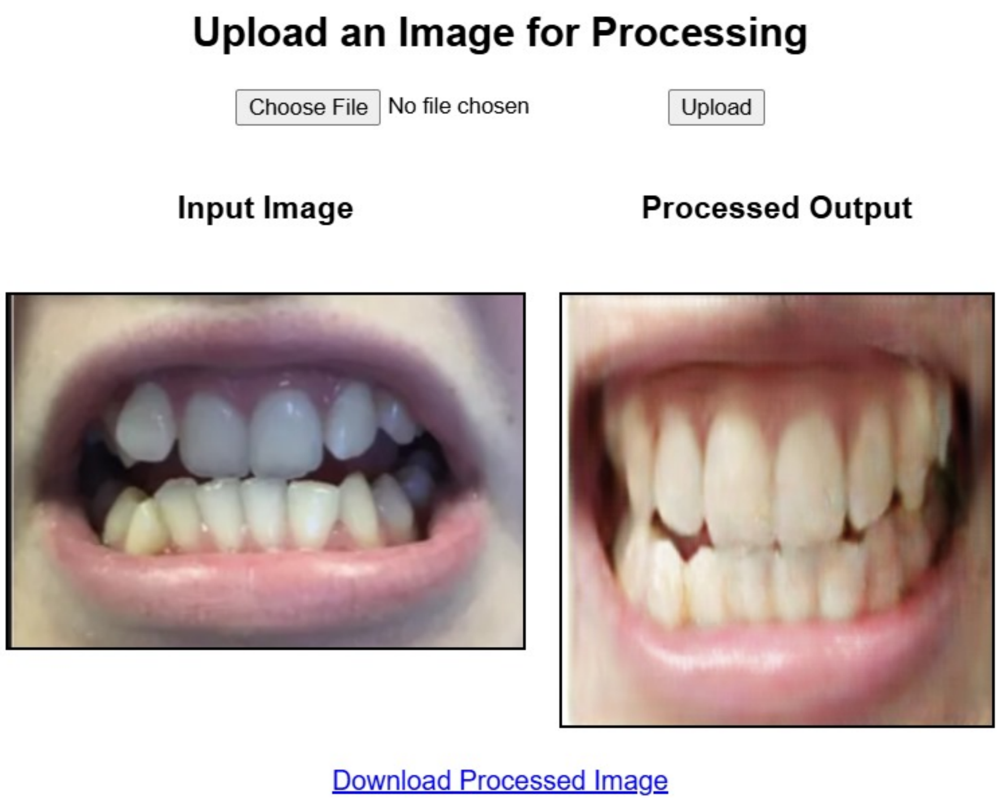

Figure 4.10: Orthodontic Treatment Simulation of Smart Dent-AI

Orthodontic Treatment Simulation page allows users to upload images of their misaligned teeth. Using AI-based image processing and deep learning models, the system generates a preview of how their teeth might look after orthodontic treatment. This feature provides users with a visual representation of potential dental improvements before opting for treatments such as braces or aligners. Additionally, users have the option to download the processed output image for future reference, making it a helpful tool for those considering orthodontic procedures.

4.2.5 Appointment Booking Page

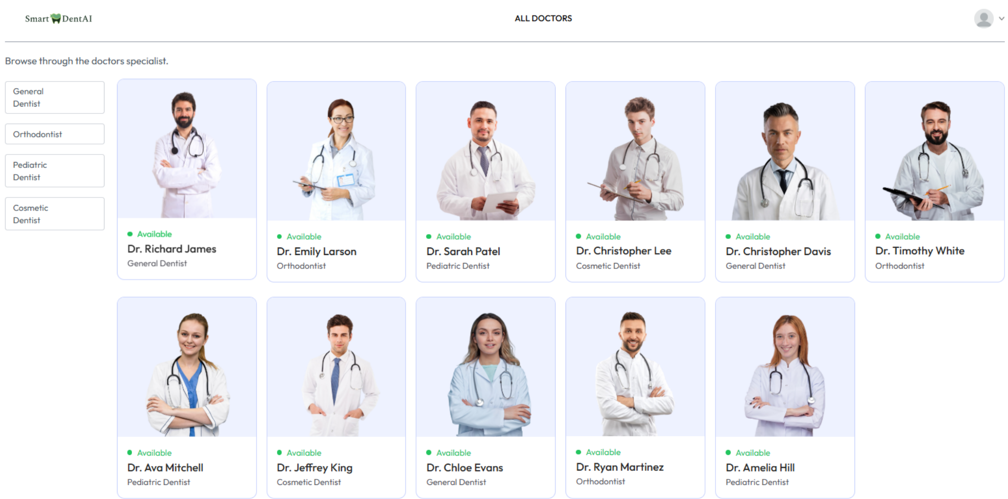

Figure 4.11: Appointment Booking Page of Smart Dent-AI

The Appointment Booking Page enables users to browse through a list of specialist doctors, including general dentists, orthodontists, pediatric dentists, and cosmetic dentists. Users can view the availability of each doctor, check their specialization, and select the most suitable professional for their dental needs. Once a doctor is chosen, the system provides an option to book an appointment at a convenient date and time, streamlining the process of accessing expert dental care.

4.2.6 Appointment Scheduling

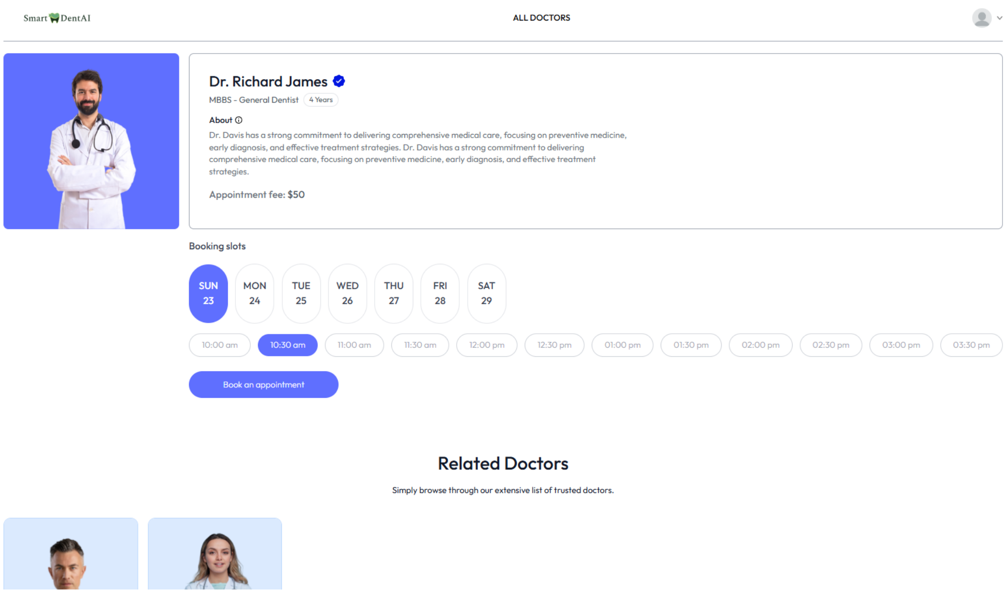

Figure 4.12: Appointment Scheduling Page of Smart Dent-AI

The Appointment Scheduling Page allows users to book a consultation with their chosen dentist by selecting a preferred date, day, and time slot. Users can view the doctor's profile, specialization, and appointment fees before finalizing their booking. Available time slots are displayed for easy selection, ensuring a smooth and convenient scheduling process. Additionally, the system suggests related doctors in case users wish to explore other options.

4.2.7 Appointment Overview Page

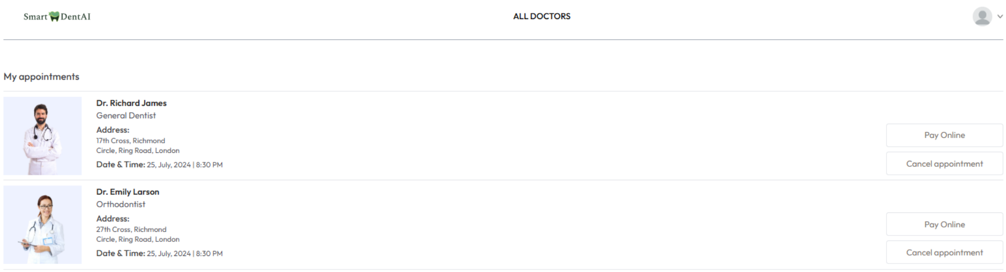

Figure 4.13: Appointment Overview Page of Smart Dent-AI

The Appointments Overview Page provides users with a summary of their scheduled appointments, including details such as the doctor's name, specialization, clinic address, and the selected date and time. Users also have the option to pay online for their consultation or cancel the appointment if needed. This page ensures easy management of upcoming consultations, allowing users to stay organized and make necessary adjustments as required.

4.3 Timeline Sem VIII

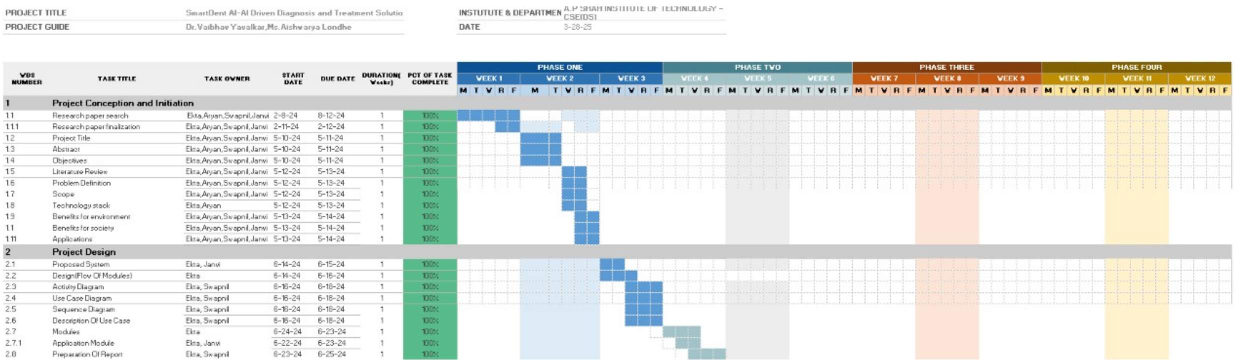

Figure 4.14: Gantt Chart Part-1

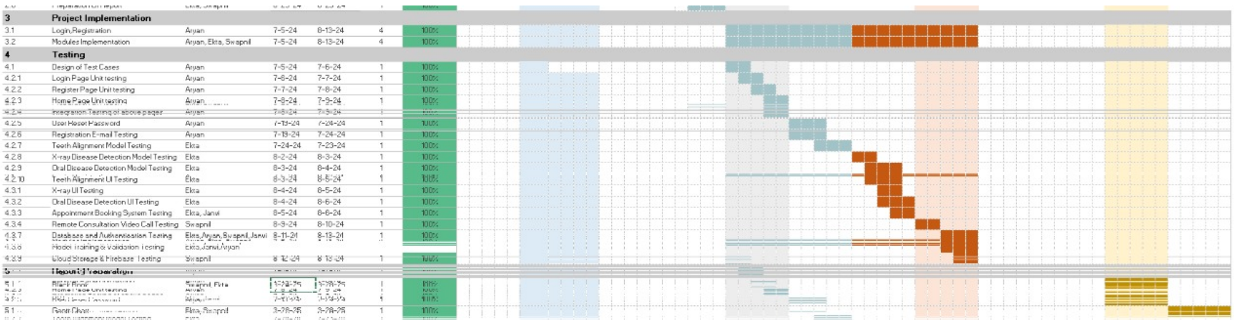

Figure 4.15: Gantt Chart Part-2

In project management, a schedule serves as a comprehensive blueprint that outlines a project's milestones, activities, and deliverables. It is not merely a list of tasks but a strategic framework that illustrates the flow of work over time, incorporating essential elements such as dependencies and resource allocations for each task. By defining these parameters, project managers can estimate start and finish dates, taking into account various factors like resource availability, budget constraints, task durations, and significant scheduled events.

The development and maintenance of the project schedule are critical components of project management, often falling under the purview of a dedicated full-time scheduler or a team of schedulers, particularly in larger and more complex projects. These professionals play a vital role in ensuring that the project remains on track by continuously updating the schedule to reflect changes, managing risks, and adjusting timelines as necessary.

A well-structured project schedule is effectively a calendar that links the various tasks that need to be accomplished with the resources assigned to carry them out. It serves as the core of the project plan, providing a clear overview of how work will be executed and organized. This clarity is crucial for committing team members and stakeholders to the project, as it outlines their responsibilities and deadlines.

Moreover, the project schedule aids in determining resource needs, enabling project managers to allocate manpower, materials, and financial resources effectively. It also acts as a checklist, ensuring that all necessary tasks are performed and completed within the established time frames. Regular monitoring and evaluation of the schedule allow for proactive adjustments, facilitating better communication among team members and helping to keep the project aligned with its goals.

Overall, the project schedule is a dynamic tool that is essential for successful project execution, enabling teams to navigate complexities, meet deadlines, and achieve desired outcomes.

Chapter 5

Testing

5.1 Software Testing

For the SmartDent-AI: AI Driven Diagnosis and Treatment Solutions, we have selected Black Box Testing as the primary software testing methodology. Black Box Testing is a standard software testing technique where the internal logic and structure of the system are not considered. Instead, testers focus on verifying the system's functionality based on expected inputs and outputs. This method ensures that the application meets the functional, usability, and reliability requirements without needing to understand the underlying machine learning models, algorithms, or database structures.

There are different techniques within Black Box Testing, including:

- **Equivalence Partitioning** – Dividing input data into different test cases to ensure comprehensive coverage.
- **Boundary Value Analysis** – Testing system behavior at input limit conditions.
- **Decision Table Testing**– Checking various input conditions and corresponding expected outputs.
- **State Transition Testing** – Validating the system's response based on different states and conditions.

Black Box Testing is ideal for Smart Dent-AI because it is a user-centric AI-powered system where the primary goal is to provide accurate and seamless healthcare services. Since the system involves deep learning-based image processing (Pix2Pix for teeth alignment, DenseNet201 for X-ray disease detection, and MobileNetV2 for oral disease detection), it is crucial to validate whether the system's predictions and outputs meet real-world medical expectations.

Additionally, SmartDent-AI includes modules such as appointment booking, remote consultation, and patient reports, which require thorough validation from a functional perspective. Black Box Testing ensures that:

1. The user receives correct predictions based on the uploaded dental images.

2. The appointment booking system functions correctly and prevents scheduling conflicts.

3. The remote consultation feature maintains video call quality and data security.

4. The system handles invalid, incomplete, or incorrect user inputs gracefully without crashing.

By employing Black Box Testing, we ensure that Smart Dental meets real-world usability standards and operates as expected across different test scenarios, improving both user experience and system reliability.

5.2 Functional Testing

Functional Testing is a type of Black Box Testing that ensures that the application's functionalities work according to the defined requirements. It focuses on testing individual features by providing appropriate inputs and verifying the expected outputs. Key types of functional testing include unit testing, integration testing, system testing, and user acceptance testing.

Functional Testing is essential for Smart Dental because the system is a multi-module AI-driven healthcare platform where each module performs a specific function. This method ensures that:

1.Teeth Alignment Prediction accurately converts misaligned teeth images into aligned ones.

2.Dental X-ray Disease Detection correctly classifies dental conditions based on input X-rays.

3.Oral Disease Detection correctly identifies oral diseases and suggests appropriate treatments.

4.Appointment Booking System successfully allows users to schedule and manage consultations.

5.Remote Consultation Module operates seamlessly with video calling and secure data transmission.

By implementing functional testing, we validate that the system meets user expectations, functions correctly in different scenarios, and provides a seamless and accurate healthcare experience.

Test Case ID	Module	Description	Steps	Expected Result	Actual Result	Status
TC-01	Teeth Alignment Prediction	Test image-to-image transformation	Upload misaligned teeth image and run model	Output aligned teeth image	Aligned output generated accurately	Passed
TC-02	Dental X-ray Disease Detection	Classify dental conditions from X-rays	Upload dental X-ray to prediction module	Shows disease class and treatment suggestion	Correct diagnosis displayed	Passed
TC-03	Oral Disease Detection	Identify oral diseases from live images	Upload or capture oral cavity image	Detects cavity, gum disease, or other issues	Output matched expected detection	Passed
TC-04	Appointment Booking	Validate slot booking and scheduling	Select dentist, time slot, and confirm booking	Confirms appointment and sends reminder	Booking successful and reminder sent	Passed
TC-05	Video Consultation	Verify remote video call setup and join	Initiate and join a video session via portal	Secure video session established	Video call connected successfully	Passed
TC-06	Data Storage	Check data storage and retrieval logic	Submit patient data	Data saved and retrievable from DB	Stored correctly in Firebase/MySQL	Passed
TC-07	Admin Dashboard	Test dashboard analytics	Login as admin and access panel	Displays analytics and logs	Data visualized accurately	Passed
TC-08	Notifications Module	Check reminder and alert system	Trigger appointment or health alert	Sends email/SMS notification	Notifications received	Passed

Test Case ID	Module	Description	Steps	Expected Result	Actual Result	Status
TC-09	Security	Validate data privacy and access control	Attempt unauthorized access to patient data	Blocked access, raise alert	Unauthorized access denied	Passed
TC-10	Treatment Recommendation	Validate AI-based treatment suggestion based on diagnosis	Input diagnosis from X-ray or oral scan	Displays recommended treatment plan (e.g., filling, scaling, braces)	Treatment suggestions matched expert guidelines	Passed

Table 5.1: Functional Testing Table

The functional testing of the Smart Dental System was conducted to validate the core modules and ensure the overall reliability and performance of the platform. Each module was tested using appropriate sample inputs, and the results were compared with expected outcomes to assess accuracy and stability.

The Teeth Alignment Prediction module (TC-01) successfully transformed misaligned teeth images into aligned versions using a trained Pix2Pix cGAN model. The Dental X-ray Disease Detection (TC-02) accurately classified conditions like tooth decay or root infections from X-rays and suggested appropriate treatment. Similarly, the Oral Disease Detection module (TC-03) identified gum issues, cavities, and other oral conditions from images captured via webcam or uploads.

The Appointment Booking module (TC-04) functioned as intended, allowing users to choose available time slots and dentists, with successful confirmation and notification. The Video Consultation module (TC-05) enabled secure remote sessions between patients and doctors without latency or connection issues. The Data Storage module (TC-06) ensured patient records were safely stored and retrieved from MySQL and Firebase databases, validating backend integration.

The Admin Dashboard (TC-07) accurately visualized real-time analytics such as patient statistics and usage logs. The Notifications module (TC-08) confirmed delivery of reminders and alerts through email or SMS. The Security module (TC-09) effectively restricted unauthorized access and ensured patient privacy by enforcing proper authentication and role-based permissions. Lastly, the Treatment Recommendation module (TC-10) provided suitable treatment plans based on diagnostic inputs, such as scaling, fillings, or orthodontic advice, aligning with dental best practices.

All test cases passed successfully, confirming the system's reliability, security, and usefulness in real-world dental healthcare scenarios. These results demonstrate that the SmartDent-AI

System is well-prepared to deliver AI-assisted dental care with accuracy, convenience, and trust.

Chapter 6

Result and Discussions

The AI-based dental diagnostic system was evaluated for three primary tasks: orthodontic analysis, X-ray interpretation, and oral condition assessment. The accuracy results for each task were as follows:

Model	**Accuracy**
Orthodontic Analysis	70%
X-ray Interpretation	92%
Oral Condition Assesment	89%

Table 6.1: Model Accuracy for each task

The system performed best in oral condition assessment, demonstrating its ability to accurately identify common dental issues such as cavities and gum health conditions. This suggests that the model effectively captures oral patterns and abnormalities through image analysis. Similarly, X-ray interpretation achieved a strong accuracy of 92%, benefiting from well-defined dental structures visible in radiographic images. However, the orthodontic analysis showed relatively lower accuracy at 70%, indicating the challenges in detecting and classifying orthodontic misalignments with high precision. The variations in tooth positioning and alignment complexity may have contributed to this lower performance.

The results highlight the potential of AI in dental diagnostics, particularly in assisting dentists with preliminary assessments. The high accuracy in oral condition assessment and X-ray interpretation suggests that deep learning models can effectively analyze dental structures and detect abnormalities. However, the lower performance in orthodontic analysis indicates the need for further improvements, particularly in data diversity and feature extraction techniques.

One key observation during model training was the steady improvement in performance over multiple epochs. The decreasing generator and discriminator losses suggest that the model effectively learned relevant patterns from the dataset. Additionally, training efficiency improved over time, with reduced processing time per epoch, making the system more viable for real-time clinical applications.

Despite these promising results, certain limitations were identified. The orthodontic module may require multi-view images or 3D dental scans to improve accuracy, as 2D images might not provide sufficient depth information for precise analysis. Another possible challenge is data imbalance, where certain dental conditions may have been underrepresented in the dataset, leading to biased predictions. Additionally, incorporating explainable AI (XAI) techniques could enhance model interpretability, allowing dentists to understand and validate the system's predictions more effectively.

Comparing the results with existing dental diagnostic approaches, our system shows a competitive edge in efficiency and automation. Traditional methods rely heavily on manual examination, which can be subjective and time-consuming. Our model reduces human error and speeds up the diagnostic process by offering automated insights. However, challenges such as dataset variability and differences in X-ray quality affect model consistency. To improve accuracy, future work can focus on dataset augmentation, transfer learning, and integrating multi-modal inputs (such as 3D scans and patient history). Additionally, real-world deployment should include continuous model retraining with real patient data to improve precision and adaptability over time.

Another critical aspect of the system's performance is its ability to provide interpretable and actionable insights for dental practitioners. The model not only classifies conditions but also highlights affected regions in X-ray images using Grad-CAM visualization, making it easier for professionals to verify predictions. This feature enhances trust and usability among dentists. Moreover, real-time symptom analysis and automated report generation improve the patient experience by reducing consultation time and providing quick preliminary assessments. However, integrating AI with clinical workflows requires regulatory approvals and acceptance from healthcare professionals, which remains a challenge for widespread adoption.

Overall, while the model has demonstrated strong performance in dental diagnostics, its accuracy and robustness can be further improved with larger datasets, advanced deep learning architectures, and real-world testing. The study highlights the potential of AI-driven dental assessments to revolutionize the field, making dental care more accessible, efficient, and data-driven.

Chapter 7

Conclusion

The AI-based dental diagnostic system presents a significant advancement in leveraging artificial intelligence for automated dental assessments. The system was designed to analyze orthodontic conditions, interpret dental X-rays, and assess oral health conditions with respective accuracies of 70%, 85%, and 89%. These results indicate that AI can be a valuable tool in supporting dental professionals by providing preliminary diagnoses, reducing workload, and enhancing the efficiency of patient care.

The high accuracy achieved in oral condition assessment and X-ray interpretation demonstrates the effectiveness of deep learning models in detecting dental anomalies. The ability to process X-ray images and provide insights into potential issues such as cavities, infections, and bone structures ensures that AI can complement the expertise of dentists. However, orthodontic analysis, with a relatively lower accuracy of 70%, suggests the need for further refinements, particularly in the area of feature extraction and dataset diversity.

Despite these promising results, challenges such as data variability, class imbalances, and the need for high-resolution images remain. The reliance on 2D images in orthodontic analysis limits the model's ability to fully understand complex dental structures, which could be better addressed using 3D imaging techniques. Moreover, the system's interpretability remains a crucial factor for adoption in clinical settings, as dentists must be able to understand and validate the AI-generated insights before making final treatment decisions.

Overall, this study highlights the potential of AI-driven solutions in dentistry, paving the way for further improvements in dental diagnostics, treatment planning, and patient care. With continuous enhancements, such systems can revolutionize how dental healthcare is delivered, making it more accessible, accurate, and efficient.

Chapter 8

Future Scope

The future scope of this AI-based dental diagnostic system is vast, with numerous possibilities for improvements and expansions. The following key areas could significantly enhance the system's functionality and impact:

- **Enhancement of Orthodontic Analysis**: To improve the accuracy of orthodontic assessments, future models can integrate multi-view imaging, such as panoramic and cephalometric X-rays. Additionally, incorporating 3D scanning technology could provide a more detailed understanding of tooth alignment and jaw structure, leading to more precise orthodontic predictions.

- **Integration of Explainable AI (XAI)**: Explainability is crucial in medical AI applications. Future iterations of the system can include XAI techniques that provide dentists with detailed reasoning behind each diagnosis. Heatmaps, feature importance scores, and decision trees could help dental professionals interpret AI-generated insights with greater confidence.

- **Real-Time Diagnostic Assistance**: Implementing real-time AI-assisted diagnostics in dental clinics can streamline patient assessments. By integrating the system with intraoral cameras and real-time processing capabilities, dentists could receive instant feedback on a patient's dental condition during examinations.

- **Personalized Treatment Recommendations**: Future versions of the system could go beyond diagnosis and provide personalized treatment suggestions based on patient history, lifestyle, and dental records. By integrating AI with electronic health records (EHRs), the system can suggest optimal treatment plans, preventive measures, and follow-up schedules.

- **Expansion to Other Dental Specialties**: The system can be extended to cover more specialized areas of dentistry, such as periodontal disease detection, oral cancer screening, and temporomandibular joint (TMJ) disorder analysis. AI-powered screening for early-stage oral cancers could be particularly impactful in reducing mortality rates through timely intervention.

- **Multi-Modal AI Integration**: Combining multiple data sources such as X-rays, intraoral scans, and patient-reported symptoms could enhance diagnostic accuracy.

Multi-modal learning approaches that integrate different types of dental data can improve the system's ability to identify complex dental conditions.

- **Cloud-Based and Mobile Applications**: Developing a cloud-based platform or mobile application would enable dentists and patients to access AI-driven dental insights from any location. A tele-dentistry feature could allow patients to upload images for preliminary assessments before scheduling in-person consultations.

- **Continuous Model Training with Feedback Loops**: Implementing a feedback loop where dentists can validate AI predictions and provide corrections would help the model continuously improve over time. This iterative learning approach ensures that the system adapts to real-world clinical scenarios and enhances its accuracy with each use.

- **Regulatory Compliance and Clinical Validation**: For AI-based dental diagnostics to be widely adopted, obtaining regulatory approvals from medical authorities is essential. Future research should focus on clinical validation through large-scale trials and collaborations with dental institutions to ensure the system meets industry standards for accuracy, reliability, and ethical considerations.

- **Integration with Robotics and Automated Dental Procedures**: The future of AI in dentistry could extend beyond diagnostics to robotic-assisted dental procedures. AI-driven robotic systems could assist in precision-based tasks such as cavity filling, dental implants, and orthodontic adjustments, minimizing human error and improving treatment outcomes.

By addressing these areas, the AI-based dental diagnostic system can evolve into a comprehensive tool that enhances patient care, supports dental professionals, and contributes to the advancement of digital dentistry. The integration of AI in dental healthcare holds great promise in making oral health assessments more efficient, accurate, and accessible to a wider population.

Bibliography

[1]Zuhal Can, Sahin Isik, and Yildiray Anagun. Cvapool: using null-space of cnn weights for the tooth disease classification. Neural Computing and Applications, 36(26):16567–16579, Sep 2024.

[2] Yanlin Chen, Haiyan Du, Zhaoqiang Yun, Shuo Yang, Zhenhui Dai, Liming Zhong, Qianjin Feng, and Wei Yang. Automatic segmentation of individual tooth in dental cbct images from tooth surface map by a multi-task fcn. IEEE Access, 8:97296–97309,2020.

[3] Yulong Dou, Lanzhuju Mei, Dinggang Shen, and Zhiming Cui. 3d structure-guided network for tooth alignment in 2d photograph, 2024.

[4] Tahereh Hassanzadeh, Daryl Essam, and Ruhul Sarker. 2d to 3d evolutionary deep convolutional neural networks for medical image segmentation. IEEE Transactions on Medical Imaging, 40(2):712–721, 2021.

[5] Tae Jun Jang, Kang Cheol Kim, Hyun Cheol Cho, and Jin Keun Seo. A Fully Automated Method for 3D Individual Tooth Identification and Segmentation in Dental CBCT . IEEE Transactions on Pattern Analysis Machine Intelligence, 44(10):6562– 6568, October 2022.

[6] Dogun Kim, Jaeho Choi, Sangyoon Ahn, and Eunil Park. A smart home dental care system: integration of deep learning, image sensors, and mobile controller. Journal of Ambient Intelligence and Humanized Computing,14(2):1123–1131, Feb 2023.

[7] Mircea Paul Muresan, Andrei R˘azvan Barbura, and Sergiu Nedevschi. Teeth detection and dental problem classification in panoramic x-ray images using deep learning and image processing techniques. In 2020 IEEE 16th International Conference on Intelligent Computer Communication and Processing (ICCP), pages 457–463, 2020.

[8] Shreyansh A. Prajapati, R. Nagaraj, and Suman Mitra. Classification of dental diseases using cnn and transfer learning. In 2017 5th International Symposium on Computational and Business Intelligence (ISCBI), pages 70–74, 2017.

[9] Devesh Saini, Richa Jain, and Anita Thakur. Dental caries early detection using convolutional neural network for tele dentistry. In 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), volume 1, pages 958–963, 2021.

[10] Zhiyang Zheng, Hao Yan, Frank C. Setzer, Katherine J. Shi, Mel Mupparapu, and Jing Li. Anatomically constrained deep learning for automating dental cbct segmentation and lesion detection. IEEE Transactions on Automation Science and Engineering,18(2):603–614, 2021.

[11] Haihua Zhu, Zheng Cao, Luya Lian, Guanchen Ye, Honghao Gao, and Jian Wu. Cariesnet: a deep learning approach for segmentation of multi-stage caries lesion from oral panoramic x-ray image. Neural Computing and Applications, 35:1–9, 01 2022.

[12]Gautam Chitnis,Vidhi Bhanushali,Aayush Ranade.A Review of Machine Learning Methodologies for Dental Disease Detection.2020.

[13]S. Sivagami, P.Chitra, G. SriRam Kailash, S.R.Muralidharan.UNet Architecture Based Dental Panoramic Image Segmentation.2020.

[14]HaihuaZhu, ZhengCao, LuyaLian1,GuanchenYe.CariesNet:a deep learning approach for segmentation of multi-stage caries lesion from oral panoramic X-ray image.2022.

[15]AsmaulHosna, Ethel Merry, Jigmey-Gyalmo, Zulfikar Alom.Transfer learning: a friendly introduction.2022.

Appendices

Detailed information, lengthy derivations, raw experimental observations etc. are to be presented in the separate appendices, which shall be numbered in Roman Capitals (e.g. "Appendix I"). Since reference can be drawn to published/unpublished literature in the appendices, these should precede the "Literature Cited" section.

Appendix I: NS2 Download and Installation

1. Download `ns-allinone-2.35.tar.gz` from `http://sourceforge.net/projects/nsnam/`
2. Place `ns-allinone-2.35.tar.gz` in your desired directory, e.g., `/home/sanchit`
3. Open Terminal and execute the following commands:

   ```
   sudo apt-get update
   sudo apt-get install automake autoconf libxmu-dev build-essential
   ```

4. Extract `ns-allinone-2.35` and navigate to the folder via Terminal:

   ```
   $ cd ns-allinone-2.35
   $ ./install
   ```

5. Set environment paths:

   ```
   $ gedit .bashrc
   ```

   Add the following lines (update path as needed):

   ```
   export PATH=$PATH:/home/aryan/ns-allinone-2.35/bin:\
   /home/aryan/ns-allinone-2.35/tcl8.5.10/unix:\
   /home/aryan/ns-allinone-2.35/tk8.5.10/unix

   export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/home/aryan/\
   ns-allinone-2.35/otcl-1.14:/home/aryan/ns-allinone-2.35/lib

   export TCL_LIBRARY_PATH=$TCL_LIBRARY_PATH:/home/aryan/\
   ns-allinone-2.35/tcl8.5.10/library
   ```

6. Apply changes:

```
$ source .bashrc
```

7. Run the validation test:

```
$ ./validate
```

8. Run NS2:

```
$ ns
```

You should see the `%` prompt if installation is successful.

Appendix II: Python and Library Installation

1. Install Python (preferably version 3.8 or above). In terminal:

```
sudo apt update
sudo apt install python3 python3-pip
```

2. Verify the installation:

```
python3 --version
pip3 --version
```

3. Create and activate a virtual environment (optional but recommended):

```
sudo apt install python3-venv
python3 -m venv myenv
source myenv/bin/activate
```

4. Install required Python libraries for face recognition:

```
pip install flask
pip install tensorflow
pip install numpy
pip install pillow
```

5. Test if everything works:

```
python3
>>> import os
>>> import traceback
>>> import google.generativeai
>>> import tensorflow as tf
>>> print("Libraries installed successfully!")
```

Publication

Paper entitled **"SmartDent AI-AI Driven Diagnosis and Treatment Solutions"** is submitted at **"IEEE 2025 Global Conference in Emerging Technology(GINOTECH), Pune"** by **"Vaibhav Yavalkar,Ekta Panchal,Aryan Palaspagar,Aishwarya Londhe, Swapnil Rathod,Janvi Sharma".**

Patent

Patent entitled **"SmartDent AI :AI Driven Diagnosis and Treatment Solutions"** has been registered with the **"Controller General of Patents, Designs and Trade Marks" (India)**, under Application Number **"202521032336"**

Copyright

Copyright entitled **"SmartDent AI :AI Driven Diagnosis and Treatment Solutions"** has been registered with the **"Copyright Office,Government of India"**, under Registration Number **"13528/2025-CO/SW"**