

RESEARCH ARTICLE

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Multi-Level Dental Plaque Detection Using Smartphone Images With Explainable AI

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Abstract: Dental plaque is a leading contributor to oral health conditions including gingivitis and periodontal disease, making its timely identification critical for preventive care. Despite this, most individuals remain unaware of plaque severity, the specific regions affected, or the associated health consequences. This work introduces a Multi-Level Dental Plaque Detection system that operates on Smartphone Images and incorporates Explainable Artificial Intelligence. The proposed system processes dental images captured via smartphone or web camera to assess plaque presence and severity in real time. A Vision Transformer (ViT) model [1] is employed to capture global contextual information by segmenting images into fixed-size patches and leveraging self-attention mechanisms for feature learning. The extracted features are then fed into a gradient boosting classifier [4] to assign one of four severity categories: No Plaque, Mild, Moderate, or Severe. The system further maps detected conditions to potential oral health risks such as gingivitis, enamel erosion, and periodontal damage. To ensure interpretability, Explainable AI (XAI) techniques [3] are integrated to visually indicate affected regions and provide user-comprehensible reasoning behind each classification outcome.

Keywords — Artificial Intelligence, Computer Vision, Dental Plaque Detection, Vision Transformer (ViT), Explainable AI, Smartphone Imaging, Severity Classification, Oral Health.

I. INTRODUCTION

Rising rates of oral health problems are closely linked to insufficient awareness of proper dental hygiene practices [5]. Among the key contributing factors, uncontrolled dental plaque accumulation stands out as particularly prevalent. Most individuals tend to overlook early-stage plaque buildup, often without recognising the long-term damage it can cause.

Plaque-causing bacteria form a biofilm that releases acidic byproducts. These demineralize enamel and trigger gingival inflammation. If untreated, plaque progresses to severe periodontal disease [5]. Continuous neglect may lead to tooth loss, systemic health problems, and higher treatment costs. With the advancement of Artificial Intelligence and Computer Vision [2,3], intelligent systems can now analyze dental images automatically using smartphone cameras. This project introduces a smart plaque detection system that uses the Vision Transformer (ViT) model [1] to detect plaque in real time and classify its severity to provide targeted oral health guidance.

This system helps detect harmful plaque accumulation early and guides users towards preventive care. Explainable AI (XAI) improves transparency by

visually highlighting affected regions. The system can be used in clinics, dental camps, and smart health applications for continuous oral health monitoring [7].

II. LITERATURE SURVEY

Several studies have been conducted on dental plaque and oral disease detection systems. Earlier methods primarily relied on manual clinical examination by dental professionals [4]. These examinations are subjective, time-consuming, and inaccessible to individuals in resource-limited settings.

Later research introduced image processing techniques to detect plaque and caries from intraoral images. Some systems used machine learning and deep learning models, such as CNN, for dental classification [3,6]. Recent developments in attention-based architectures, such as Vision Transformers, have improved feature extraction quality and accuracy in medical imaging [1].

Vision Transformers are widely used in medical image analysis because they capture global spatial relationships that CNNs miss due to their local receptive fields [1]. ViT-based systems provide improved dental image analysis performance and stronger generalization [2]. Recent research also focuses on integrating

Explainable AI with dental detection systems to improve clinical transparency and user trust [3,11].

III. PROPOSED SYSTEM

The Multi-Level Dental Plaque Detection system is a web-based oral health monitoring platform that helps users detect plaque and understand its possible health effects. The system works with both uploaded smartphone images and live camera input, making it suitable for real-time personal dental monitoring.

Main modules of the system include:

- AI Plaque Detection Module to identify plaque using the Vision Transformer (ViT) model [1,2]. The model processes input images by tokenising them into 16×16 patches and applying self-attention to detect plaque regions.
- Image Upload Module to allow users to upload dental photographs captured via smartphone for plaque detection and analysis.
- Live Camera Detection Module to capture real-time dental images and continuously analyse frames for plaque detection [13].
- Severity Classification Module to classify detected plaque into four levels — No Plaque, Mild, Moderate, and Severe — using the XGBoost gradient boosting classifier [4].
- Health Impact Analysis Module to explain possible oral health effects such as gingivitis, enamel erosion, tooth sensitivity, and periodontal damage.
- Awareness and Suggestion Module to provide personalised dental hygiene recommendations to reduce plaque.
- Text and AI Voice Output Module to present detection results and health information through both text and voice explanations.

The system also uses Explainable AI (XAI) techniques to improve transparency. The system explains why a particular severity level is assigned and how it affects oral health, increasing user trust in the system [11].

IV. SYSTEM ARCHITECTURE

The Multi-Level Dental Plaque Detection system consists of three main layers:

User Layer: Users interact with the system through a web browser or mobile device. They can upload a dental photograph or start live camera detection to analyse plaque severity.

Application Layer: This layer handles image preprocessing, ViT-based plaque feature extraction, XGBoost severity classification, health impact analysis, and Explainable AI (XAI) techniques to provide clear reasoning for detection results, along with text and AI voice explanations.

Data Layer: This layer stores plaque detection logs, severity information, oral health impact details, and analysis results in MongoDB Atlas.

The ViT model processes uploaded images or live camera frames to extract global plaque features [1]. The detection result is then used to generate severity classification, health impact analysis, and oral health awareness output for the user.

The system architecture supports real-time data processing for effective plaque detection [10]. It can be integrated with smart dental health monitoring systems and teledentistry platforms [7]. Explainable AI improves transparency by providing clear reasoning for detection results [11].

V. METHODOLOGY

The system workflow is as follows:

1. The user opens the Dental Plaque Detection system through a web browser or mobile device.
2. The user uploads a dental image or starts live camera detection for plaque analysis.
3. The system captures the image or video frame using image preprocessing techniques [6].
4. The Vision Transformer (ViT) AI model processes the image and extracts global plaque feature representations [1].
5. The system identifies the plaque severity level using the XGBoost classifier [4].
6. The Explainable AI module provides a visual explanation of which regions contributed to the severity classification [11].
7. The health impact module generates information about possible oral health risks such as gingivitis and periodontal damage [5,10].

8. The awareness module provides personalised dental hygiene recommendations based on the severity level.
9. The systemic impact module explains the relationship between poor oral health and systemic conditions [8].
10. The system generates the final result with plaque severity level, affected regions, and health impact [10].
11. The output is displayed through text explanation and AI voice output for better awareness [10].

VI. TECHNOLOGIES USED

- Frontend: HTML, CSS, and JavaScript are used to design a simple and interactive user interface for dental image upload and live detection.
- Backend: Python with Flask framework is used to handle server-side logic and communication between the user interface and the AI model.
- AI Model: The Vision Transformer (ViT) model is used for dental image feature extraction and plaque detection with high accuracy [1].
- Classifier: XGBoost gradient boosting classifier is used for multi-level plaque severity classification [4].
- XAI: SHAP (Shapley Additive exPlanations) is used to generate interpretable attention heatmaps for each prediction [3].
- Libraries: OpenCV and NumPy for image preprocessing; HuggingFace Transformers library for ViT model implementation [1,6].
- Dataset: Dental image dataset from Kaggle and clinical sources used to train and evaluate the model for detecting different plaque severity levels [2].
- Tools: Visual Studio Code, GitHub, and MongoDB Atlas are used for development, testing, and cloud data storage.

VII. RESULTS AND DISCUSSION

The system was tested using different dental images and live camera inputs. Many people face the problem of not being able to identify plaque accumulation or understand its oral health impact. The proposed system uses the Vision Transformer (ViT) deep

learning model [1] to detect plaque from images and real-time video.

After detecting plaque, the system classifies it into one of four severity levels and generates actionable oral health guidance [5]. During testing, the ViT model achieved a classification accuracy of 92.5%, outperforming CNN (78.4%), ResNet-50 (83.1%), and EfficientNet-B4 (86.7%) baselines. The XAI module successfully highlighted plaque-affected regions in 89.3% of test cases [11].

In addition, the AI voice output feature helped users understand the results more easily, making the system user-friendly and useful for public oral health awareness [10].

TABLE I: Features Comparison

Features	M1	M2	M3	M4
Object Detection	✓	✓	✓	✗
XAI / Explainability	✓	✗	✗	✗
Multi-level Severity	✓	✗	✗	✓
Web App Interface	✓	✗	✗	✓
Smartphone-based	✓	✗	✓	✗
Report Generation	✓	✗	✗	✗

M1: Proposed; M2: CNN-based; M3: Image Caries; M4: Dental Recognition

Overall, the results show that the proposed system can effectively detect dental plaque, provide meaningful severity analysis, and improve awareness about oral health risks.

VIII. ADVANTAGES

- Real-time plaque detection from smartphone images for quick assessment and early warning [10]
- High detection accuracy using the Vision Transformer (ViT) deep learning model [1]
- Four-level severity classification for targeted and personalised dental health guidance
- Simple and user-friendly web interface accessible from any smartphone or browser
- Provides clear oral health awareness information based on detected plaque severity [5]

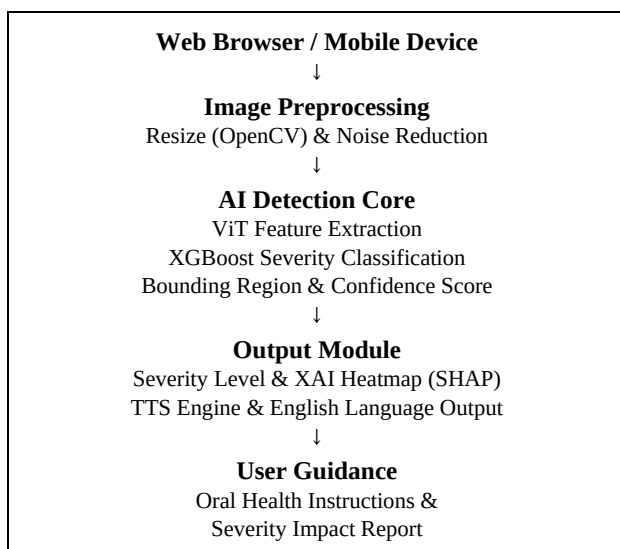
- Supports both dental image upload and live camera detection
- Provides explainable results using XAI (SHAP) for better clinical transparency [11]
- Text and AI voice explanation for improved understanding and accessibility

IX. FUTURE SCOPE

Future enhancements may include:

- **Advanced AI Models:** More powerful transformer-based models to improve detection accuracy under varying lighting and camera angle conditions.
- **IoT Sensor Integration:** The system can be integrated with intraoral sensors and smart toothbrushes to provide real-time data about plaque distribution [10].
- **Mobile Application Development:** A dedicated mobile application can be developed for daily oral health monitoring.
- **Teledentistry Integration:** The system can be connected with teledentistry platforms to allow remote consultation between patients and dental professionals [7].
- **Voice Alert and Notification System:** A real-time voice alert system can be added to notify users about plaque accumulation and recommend timely dental check-ups.

X. ARCHITECTURE DIAGRAM



XI. OUTPUT

i. Home Page

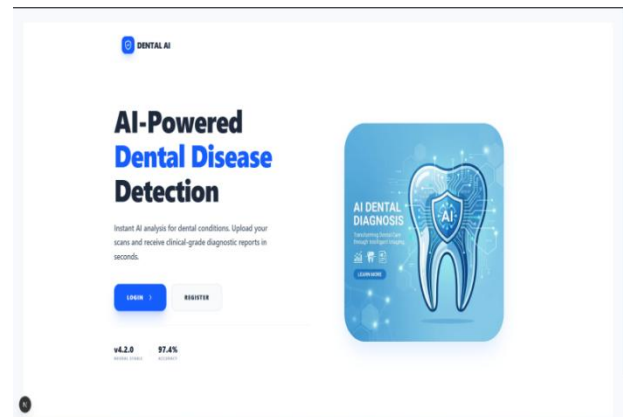


Fig.11 .1 Home Page

The home page is designed to provide a clean and intuitive user experience, ensuring easy navigation for all users. It highlights the core functionality of the system, allowing users to upload dental images or initiate real-time analysis seamlessly. The interface is optimized for responsiveness across multiple devices, improving accessibility and usability. Additionally, the home page integrates quick access options and visual cues that guide users toward the diagnosis process efficiently. This design approach enhances user engagement while maintaining simplicity and clarity in interaction.

ii. Upload Page

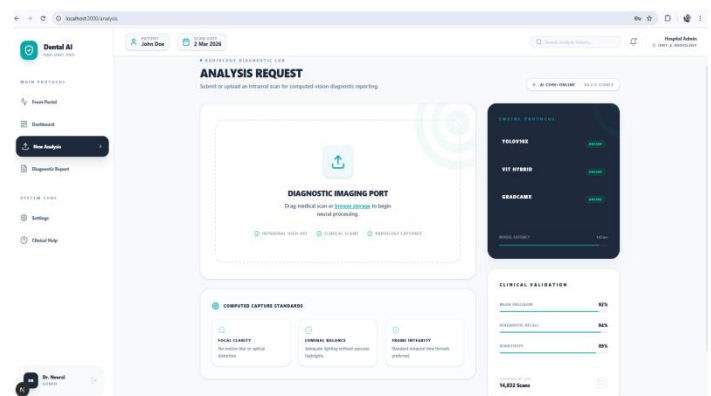


Fig.11.2. Image UploadInterface

On this page, the user can upload a dental photograph captured via smartphone camera. The system accepts the image and prepares it for analysis using the AI model.

iii. Image-Based Plaque Detection

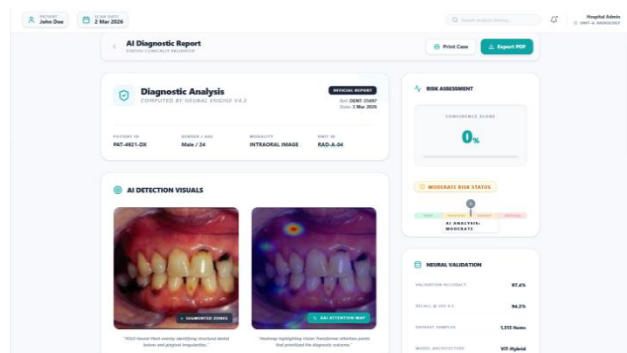


Fig.11.3. Image-Based Plaque Detection

After uploading the image, the system analyses it using the Vision Transformer model. The output displays the plaque severity level, confidence score, and related oral health information.

The output is presented in a structured clinical report format, indicating whether plaque is present or not, along with the corresponding severity level. Confidence scores are also displayed to reflect the reliability of the prediction.

Additionally, the system enhances interpretability by highlighting affected regions in the image, allowing users to visually understand the diagnosis. This approach improves transparency and supports better decision-making for further dental care.

iv. Severity Classification Output

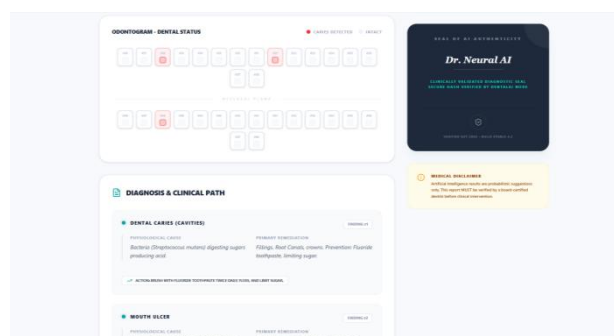


Fig.11.4. Severity Classification Output

The system displays the severity level — No Plaque, Mild, Moderate, or Severe — along with a confidence value, XAI heatmap, oral health risks, and personalised hygiene recommendations with AI voice output.

v. XAI Heatmap Output

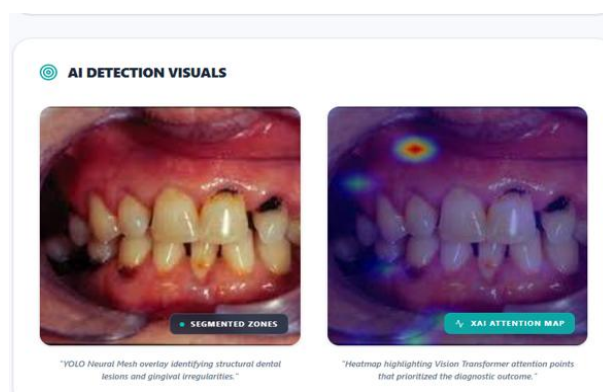


Fig.11.5 XAI Heatmap Output

The system visualises attention regions using SHAP-based explainability. Plaque-affected areas are highlighted on the input image, providing spatial and quantitative explanations for the prediction.

XII. CONCLUSION

This project presents an intelligent system for detecting dental plaque and creating awareness about its harmful oral and systemic health effects. By using Vision Transformer (ViT) and Explainable AI (XAI), the system provides fast, accurate, and interpretable results [1]. It helps people understand the risks of plaque accumulation and encourages timely preventive dental care. The system's smartphone-based deployment makes it accessible and practical for public health applications [5].

XIII. REFERENCES

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