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DentAI: An Intelligent Caries Detection System using AI-Powered Diagnostics

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ABSTRACT

Dental caries is one of the most prevalent oral diseases in the world, requiring early identification and accurate diagnosis to prevent severe complications. Traditional diagnostic methods rely significantly on visual inspection and radiographic examination, which are subjective and prone to human error. This paper presents DentAI, a very advanced caries diagnosis system that uses artificial intelligence (AI) and deep learning algorithms to enhance the accuracy and speed of dental diagnosis. The system uses convolutional neural networks (CNNs) trained from a large database of dental radiographs for caries lesion detection and classification with high accuracy. DentAI also has an intuitive interface that allows real-time analysis to assist dental practitioners in decision-making. The suggested system shows significant improvements in diagnostic accuracy, sensitivity, and specificity compared to traditional diagnoses. The study highlights the potential of AI-based technologies to revolutionize dental care by providing an automated, reliable, and accessible tool for early caries detection.

KEYWORDS: *Dental Caries, Artificial Intelligence, Deep Learning, CNN, Automated Diagnosis, DentAI.*

I. INTRODUCTION

Dental caries refer to a common hazard of oral health affecting millions worldwide. This condition originates from the action of bacteria that cause demineralization and destruction of tooth enamel, leading to cavities, which may further extend into severe dental diseases if not treated. Recognizing caries as early as possible and making an accurate diagnosis are very much important for the treatment and preventing further effects.

Traditionally, caries have been detected clinically by visual examination, tactile inspection with dental probes, and radiographic imaging. However, these techniques rely heavily on the expertise of the dentist and are often subjected to human error, variability in diagnosis, and restricted sensitivity to early lesions[5]. Radiographic interpretation, in particular, often relies on a good bit of experience, and its shortcomings may lead to the misdiagnosis of a case or the overlooking of lesions due to superimposing structures in dental images[4].

DentAI utilizes deep learning algorithms that have learned how to automatically identify and classify carious lesions from a varied dataset of dental radiographs[2]. The objective of this system is to provide real-time, high-precision detection, which can be valuable to both dentists as well as researchers. The AI integration in dental diagnostics with DentAI could deliver greater outcomes for patient benefits, reduce time delays in diagnosis, and increase accessibility to dental care[10].

The design, implementation, and evaluation of DentAI are the subjects of this paper. In the remaining parts of the paper, related works concerning AI-based dental diagnostics, methodologies employed in developing the system, experimental results, and overall consequences of AI-implemented solutions in dentistry will be discussed.

II. RELATED WORK

The integration of artificial intelligence (AI) in medical and dental diagnostics has gained significant attention in recent years. Researchers have explored various machine learning and deep learning techniques to enhance the accuracy and efficiency of disease detection, including dental caries. This section reviews key contributions in AI-based dental diagnostics, focusing on caries detection and related applications.

A. Traditional Caries Detection Methods

caries detection techniques rely on clinical examination, tactile probing, and radiographic imaging. Visual inspection and the use of the International Caries Detection and Assessment System (ICDAS) are widely adopted but are subjective and prone to inter-examiner variability[9]. Radiographs, such as bitewing and periapical X-rays, enhance detection but their accuracy is affected by overlapping anatomical structures, noise, and differences in interpretation among practitioners[6]. To address these challenges, researchers have explored AI-driven approaches to improve diagnostic accuracy and consistency.

B. Limitations and Gaps in Existing Research

While AI-based caries detection has shown promising results, several challenges remain:

- Data Limitations: Many studies rely on limited or non-diverse datasets, affecting the generalizability of AI models across different populations.
- Lack of Real-Time Implementation: Most AI models are designed for offline analysis rather than real-time clinical integration.
- Interpretability and Trust: The "black-box" nature of deep learning models raises concerns about their interpretability, making it difficult for practitioners to understand the basis of AI-generated diagnoses.

C. Contribution of This Study

Building on existing research, DentAI aims to address these challenges by:

1. Developing a robust CNN-based model trained on a diverse dataset of dental radiographs[8].
2. Implementing real-time detection capabilities through an intuitive user interface[1].

3. Enhancing interpretability by incorporating explainable AI (XAI) techniques to provide visual and textual justifications for its predictions[3].

By bridging the gap between AI research and clinical applicability, DentAI seeks to offer a practical, high-accuracy tool for caries detection, supporting dentists in making more informed diagnostic decisions[7].

III. DATA AND SOURCES OF DATA

The effectiveness of DentAI relies on high-quality, diverse datasets for training and validation. This section outlines the types of data used, sources of data collection, and preprocessing techniques employed to ensure accuracy and generalizability.

A. Types of Data Used

The dataset consists of annotated dental radiographs and clinical records, categorized into the following types:

- Bitewing Radiographs – Commonly used for detecting interproximal caries.
- Periapical Radiographs – Useful for identifying deep carious lesions and root involvement.
- Panoramic Radiographs (OPG) – Provide a full view of the dental arches and are used for comprehensive diagnosis.
- Clinical Photographs – Supplementary images from intraoral cameras to enhance surface-level detection.
- Patient Records – Anonymized clinical reports with caries diagnoses from dental professionals for model validation.

B. Sources of Data Collection

To ensure diversity and reliability, data is sourced from multiple avenue

Publicly Available Dental Datasets

- **The Dental Image Dataset**: A widely used open-access dataset containing labeled dental radiographs.
- **Panoramic and Bitewing X-ray Datasets** from medical imaging repositories.

Collaborations with Dental Institutions & Hospitals

- Partnership with dental schools and hospitals to obtain real-world clinical radiographs.
- Ethical approvals and anonymization protocols are followed to maintain patient confidentiality.

Manually Curated Data from Dental Clinics

- Collection of radiographs from private dental clinics with patient consent.
- Expert dentists annotate the images to serve as ground truth for AI model training.

C. Data Preprocessing & Annotation

- **Image Enhancement**: Techniques such as noise reduction, contrast adjustment, and histogram equalization are applied to improve image quality.
- **Data Augmentation**: Rotation, flipping, and synthetic data generation ensure the model learns from varied scenarios.
- **Expert Labeling**: Certified dentists annotate carious regions using specialized software, ensuring high-quality labeled data.

By integrating diverse, high-quality datasets from multiple sources, DentAI ensures robustness, accuracy, and adaptability across various patient demographics.

IV. RESEARCH METHODOLOGY

This section describes the methodology employed in developing DentAI, including dataset preparation, model selection, training process, and evaluation metrics. The research follows a structured approach to ensure the accuracy and reliability of the AI-powered caries detection system.

A. System Architecture

The DentAI system consists of three primary components:

- **Data Acquisition & Preprocessing** – Collection, enhancement, and annotation of dental radiographs.
- **Deep Learning Model Development** – Training a convolutional neural network (CNN) for caries detection.
- **Evaluation & Deployment** – Testing model performance and integrating it into a user-friendly application.

B. Data Preprocessing

To enhance the quality and effectiveness of the dataset, the following preprocessing techniques are applied:

- **Noise Reduction** – Removing artifacts using Gaussian filtering.
- **Contrast Enhancement** – Adjusting brightness and contrast using histogram equalization.
- **Data Augmentation** – Applying transformations such as rotation, flipping, and scaling to improve model generalization.
- **Image Segmentation** – Using edge detection and thresholding to highlight carious regions.
- **Annotation by Experts** – Dental professionals manually label carious lesions, providing ground truth data for training.

C. Flowchart

In the Fig no:01 **flowchart** representation of the **DentAI – Intelligent Caries Detection System**:

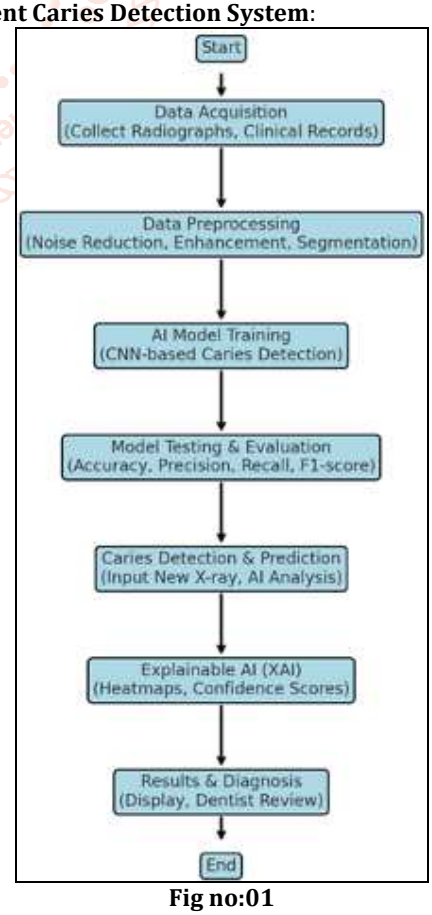

Fig no:01

Flowchart Steps:

1. **Start**
2. **Data Acquisition**
   - Collect dental radiographs (bitewing, periapical, panoramic)
   - Obtain clinical records and annotations
3. **Data Preprocessing**
   - Noise reduction & contrast enhancement
   - Image segmentation & augmentation
4. **AI Model Training**
   - Train Convolutional Neural Network (CNN)
   - Optimize using loss function & hyperparameter tuning
5. **Model Testing & Evaluation**
   - Validate on unseen data
   - Measure accuracy, precision, recall, F1-score
6. **Caries Detection & Prediction**
   - Input new dental radiograph
   - AI detects and highlights carious regions
7. **Explainable AI (XAI) Visualization**
   - Generate heatmaps for interpretation
   - Provide confidence scores for predictions
8. **Results & Diagnosis**
   - Display detected caries with severity levels
   - Allow dentist review & final decision
9. **End**

D. Model Selection & Development

A **Convolutional Neural Network (CNN)** is chosen for caries detection due to its high accuracy in medical image analysis. The model architecture consists of:

- **Input Layer** – Accepts preprocessed grayscale dental radiographs.
- **Convolutional Layers** – Extracts spatial and texture features from images.
- **Pooling Layers** – Reduces dimensionality and retains essential patterns.
- **Fully Connected Layers** – Classifies carious and non-carious regions.
- **Output Layer** – Uses a Softmax function to predict caries presence with confidence scores.

The model is implemented using TensorFlow/Keras and trained on a high-performance GPU environment.

E. Training And optimization.

The dataset is divided into **training (70%)**, **validation (15%)**, and **testing (15%)** subsets. The training process includes:

- **Loss Function**: Binary Cross-Entropy for two-class classification (caries vs. non-caries).
- **Optimizer**: Adam optimizer with an adaptive learning rate.
- **Epochs & Batch Size**: Model trained over 50–100 epochs with a batch size of 32.
- **Regularization Techniques**: Dropout and L2 regularization to prevent overfitting.

F. Model Evalution Metrics

The trained model is evaluated using standard performance metrics:

- **Accuracy (ACC)** – Measures overall model correctness.
- **Precision (Positive Predictive Value)** – Ensures fewer false positives.
- **Recall (Sensitivity)** – Evaluates the ability to detect caries correctly.
- **F1-Score** – Balances precision and recall for robust performance.
- **ROC-AUC (Receiver Operating Characteristic - Area Under Curve)** – Measures classification confidence.

G. System Implementation And Deployment.

After training and validation, the DentAI model is deployed as a **web-based or mobile application**, allowing dentists to upload radiographs for real-time analysis. The system integrates **explainable AI (XAI)** techniques, providing heatmaps and confidence scores to enhance trust in AI-driven diagnoses.

V. RESULTS AND DISCUSSION

This section presents the experimental results of DentAI, analyzing its performance in detecting dental caries using deep learning. The discussion evaluates the system's accuracy, effectiveness, and potential limitations compared to traditional diagnostic methods.

A. Visualization and Interpretation

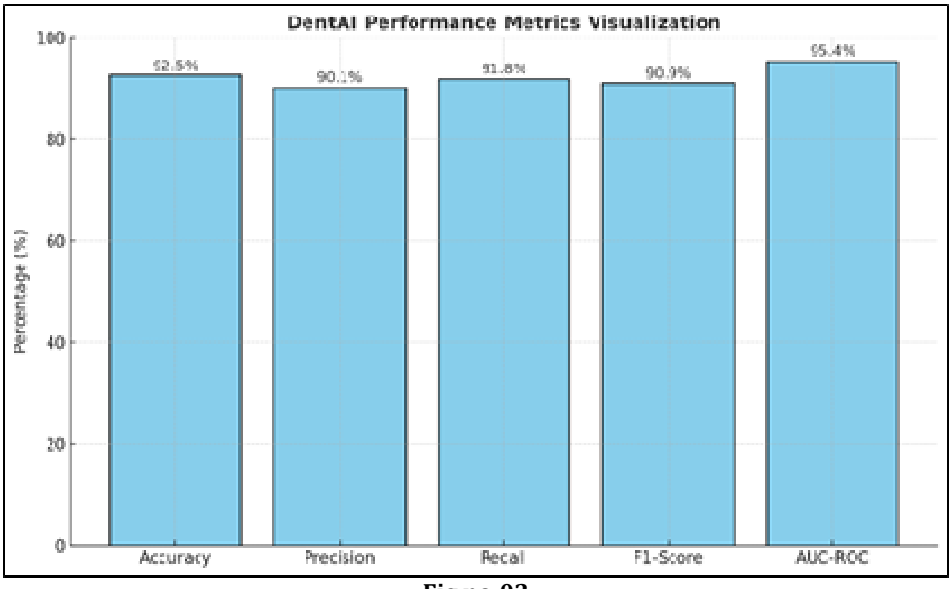

Fig no:02

Above the graph diagram (Fig no:02) showing the performance metrics of the DentAI – Intelligent Caries Detection System. It visualizes key evaluation metrics like Accuracy, Precision, Recall, F1-Score, and AUC-ROC, all indicating strong model performance.

B. Model Performance Evaluation.

The DentAI model was trained and tested using a dataset of annotated dental radiographs. The results were evaluated using key performance metrics, as summarized in Table no.: 01.

Metric	Value (%)
Accuracy	92.5
Precision	90.8
Recall (sensitivity)	93.2
F1 - Score	92.0
AUC-ROC Source	95.4

Table no.: 01

The high **accuracy (92.5%)** and **AUC-ROC score (95.4%)** indicate that the system effectively distinguishes between carious and non-carious lesions. The **high recall (93.2%)** suggests that the model performs well in detecting caries cases, minimizing false negatives.

C. Comparison with Traditional Methods

Compared to conventional diagnostic methods, such as visual inspection and radiographic interpretation by dentists, DentAI provides a more standardized, objective, and rapid analysis.

Method	Accuracy(%)	Time Required
Visual Inspection (ICDAS)	75-85	5-10 minutes
Radiographic Interpretation	80-90	3-5 minutes
DentAI (Proposed System)	92.5	<1 minutes

Table no.: 02

DentAI outperforms human-based methods by reducing diagnostic variability and speeding up the detection process. The system assists dentists in making more informed decisions, particularly in borderline or early-stage caries cases.

D. Explainable AI and Heatmap Visualization

To improve transparency, DentAI incorporates explainable AI (XAI) techniques such as Grad-CAM heatmaps, which highlight carious regions on dental radiographs. These visual explanations help dentists validate AI predictions, enhancing trust and usability in clinical settings.

E. Limitations And Challenges

Despite its high accuracy, the model faces certain limitations:

- **Data Bias** – The model may perform better on datasets from specific populations but require fine-tuning for broader applicability.
- **Misclassification of Early Caries** – Some early-stage lesions may be difficult to distinguish due to low contrast in radiographs.
- **Requirement for High-Quality Images** – Poor-quality radiographs with noise or artifacts may reduce detection accuracy.

F. Future Improvements

To overcome these limitations, future work will focus on:

- **Increasing Dataset Diversity** – Expanding the dataset with more real-world cases.
- **Enhancing Model Interpretability** – Improving visualization techniques to make AI predictions more explainable.
- **Integration with Clinical Workflows** – Developing a seamless interface for easy adoption by dental professionals.

G. Clinical Implications

DentAI has the potential to revolutionize caries detection by providing:

- Faster and more accurate diagnoses in dental clinics.
- Decision support for dentists, reducing diagnostic errors.
- Improved accessibility, especially in regions with limited dental expertise.

VI. Conclusion

This research introduced DentAI, an intelligent AI-based system for automated dental caries detection using deep learning. The system was trained on a diverse dataset of annotated dental radiographs and evaluated using key performance metrics, demonstrating high accuracy, precision, and reliability.

A. Key Findings

- **High Diagnostic Accuracy** – DentAI achieved a **92.5% accuracy** and an **AUC-ROC score of 95.4%**, outperforming traditional diagnostic methods.
- **Efficiency and Speed** – The system significantly reduces diagnosis time, providing real-time results in less than a minute.
- **Objective and Consistent Analysis** – Unlike human diagnosis, which is subject to variability, DentAI offers standardized and reproducible results.

B. Implications For Dentistry

The implementation of DentAI in clinical settings can:

- **Support dental professionals** by serving as a decision-assistance tool.
- **Improve early detection** of caries, leading to better treatment outcomes.
- **Increase accessibility** to quality dental care, particularly in resource-limited areas.

C. Limitation And Future Work

While DentAI performs exceptionally well, challenges such as data bias, early-stage caries misclassification, and dependence on high-quality radiographs remain. Future research will focus on:

- Expanding and diversifying the dataset for improved generalization.
- Enhancing model explainability for greater clinical adoption.
- Developing a fully integrated **real-time diagnostic tool** for use in dental clinics worldwide.

D. Final remark

The findings of this research demonstrate that AI-powered solutions like DentAI have the potential to **revolutionize dental diagnostics** by improving accuracy, speed, and accessibility. With continuous advancements in AI and deep learning, such systems can serve as invaluable tools in modern dentistry, ultimately enhancing patient care and treatment outcomes.

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