SMART ELECTRONIC TOOTHBRUSH FOR PLAQUE DETECTION AND REMOVAL USING IMAGE PROCESSING AND ARTIFICIAL INTELLIGENCE

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Keywords:
Electronic toothbrush, plaque detection, fluorescence imaging, image processing, machine learning, actuation, oral hygiene, sensors.

Introduction:
Oral hygiene is a cornerstone of overall health. Dental plaque a biofilm of bacteria and extracellular matrix accumulates on teeth surfaces and is strongly associated with caries and periodontal diseases. Effective plaque removal takes sufficient time, pressure, coverage, and technique. Regular toothbrushes do not provide any objective feedback relating to presence or coverage of the plaque; the electric toothbrushes enhance mechanical cleaning and yet not sensing and intelligent. Electronic brushes are also provided with sensors, image/signal processing, and adaptive actuation to (1) machine learning (ML) and adaptive actuation to identify presence and location of plaque, (2) give real-time instructions to the user and (3) adjust the brushing (speed, pressure, oscillation pattern) to maximize the removal without causing tissue damage. This survey sorts out previous and emerging work into four major technical areas:
1) Plaque detection: Piezoelectric (optical, fluorescence) sensing (impedance, acoustic, pressure).
2) Localization pipelines: Image and signal processing pipelines and quantification.
3) Classification, segmentation and AI/ML models: guidance and integrations with embedded systems.
4) Actuation and control strategies: We also cover integrations (embedded systems, mobile apps), evaluation metrics, datasets and experimental protocols, practical challenges, safety and regulatory considerations, and future research directions.

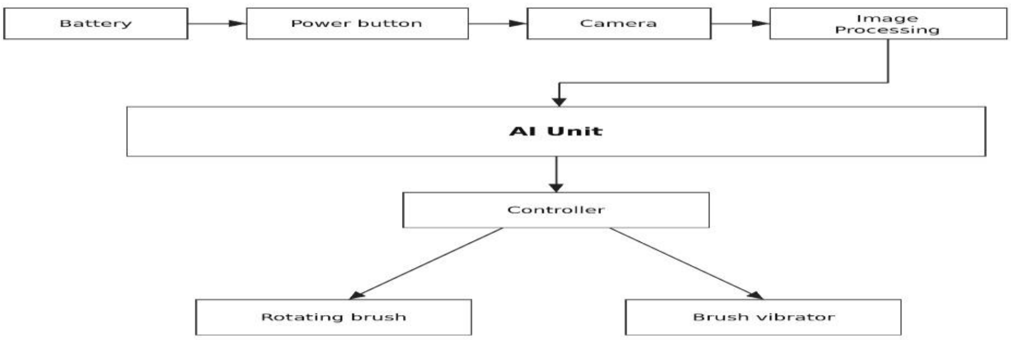


Figure 1: Block Diagram of Electronic Toothbrush

- for home oral-care monitoring

Objectives:

1. To review and compare sensing technologies used for dental plaque detection in electronic toothbrush systems.
2. To analyze image/signal processing and AI techniques for plaque localization, classification, and user guidance.
3. To examine adaptive actuation and control strategies for improving brushing effectiveness and safety.

Methodology:

It represents an intelligent, vision-based automated system and designed to perform actions automatically based on visual input and intelligent decision-making

1.Power Supply & Activation:
The battery supplies power to the system, and the power button turns the device ON.

2.Image Acquisition & Processing:
The camera captures images of the teeth surface. These images are sent to the image/signal processing unit, where noise removal and feature extraction are performed.

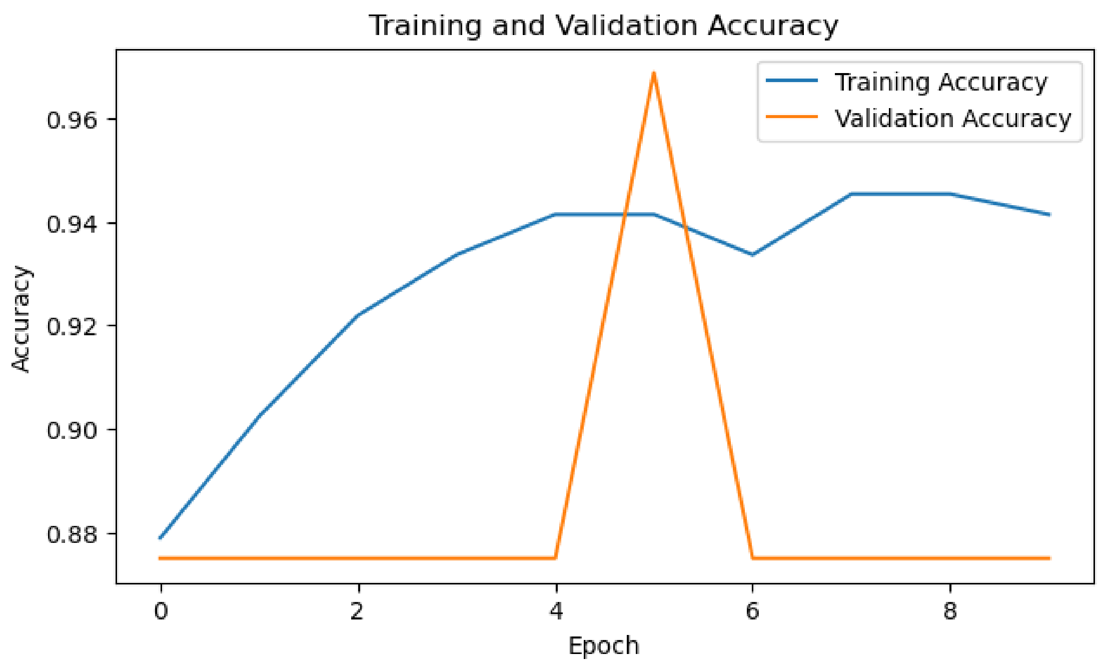
3.AI Unit (Decision Making):
The processed data is sent to the AI unit, which analyzes the images to detect plaque and determine required brushing actions.

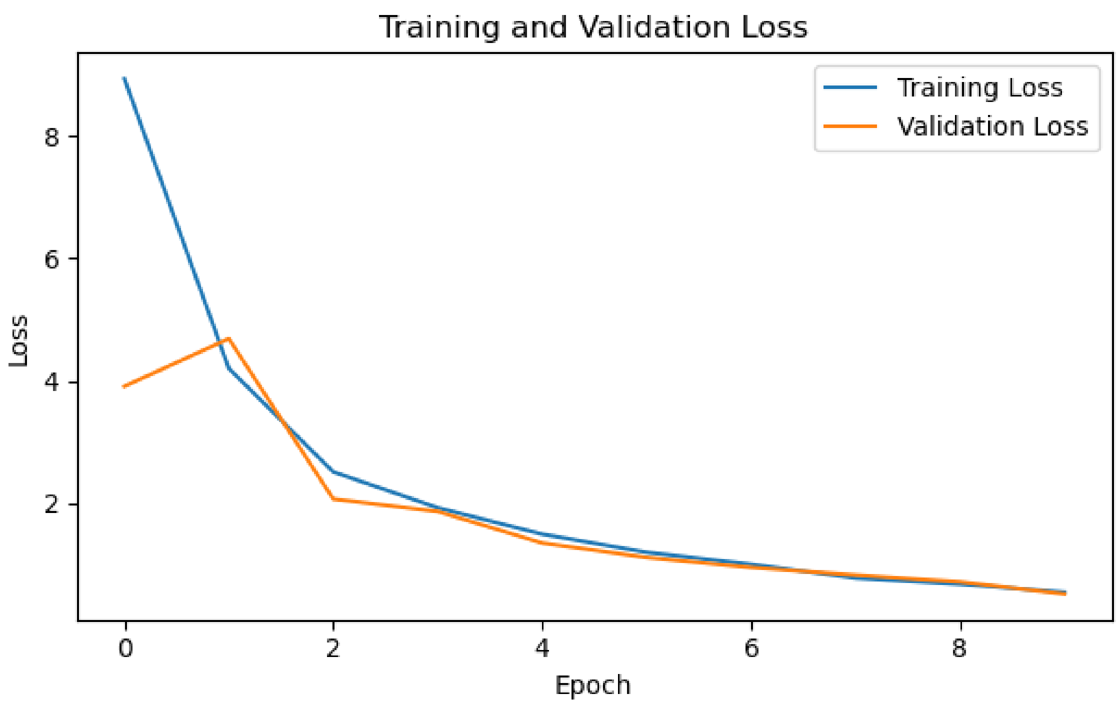
4. Controller & Actuation:
The controller receives commands from the AI unit and controls the actuators:
Rotating brush – adjusts brushing motion for cleaning.
Brush vibrator – provides vibration intensity for effective plaque removal

Result and Conclusion:

Result:

YOLOv8 is a real-time object detection model that provides both classification and localization of dental issues, making it highly suitable for smart toothbrush systems, while recent AI research models such as transformer-based architectures offer higher accuracy by capturing global image relationships but require more computational resources and are less suitable for real-time applications; in contrast, TensorFlow-based classification models focus only on identifying the presence of conditions without localization, making them useful for severity analysis but not for precise detection, and therefore a combination of YOLOv8 for detection and TensorFlow for classification provides an efficient and practical solution for intelligent dental plaque detection systems, where the dataset consists of approximately 2500 dental images and the proposed model achieves an accuracy of around 94%.





Class	Precision (P)	Recall (R)	mAP50	mAP50-95
Overall (All)	0.829	0.365	0.450	0.311
Tooth	0.901	0.959	0.979	0.873

Cavity	0.946	0.375	0.436	0.207
Caries	0.469	0.125	0.187	0.099
Crack	1.000	0.000	0.199	0.063

Figure : Model Performance Summary

DETECT PATTERN

✓ NORMAL - NO PLAQUE ✓

IOT Signal Sent: **0**

Figure: Training Batch 0 (Augmented)

Figure: Training Batch 1 (Augmented)

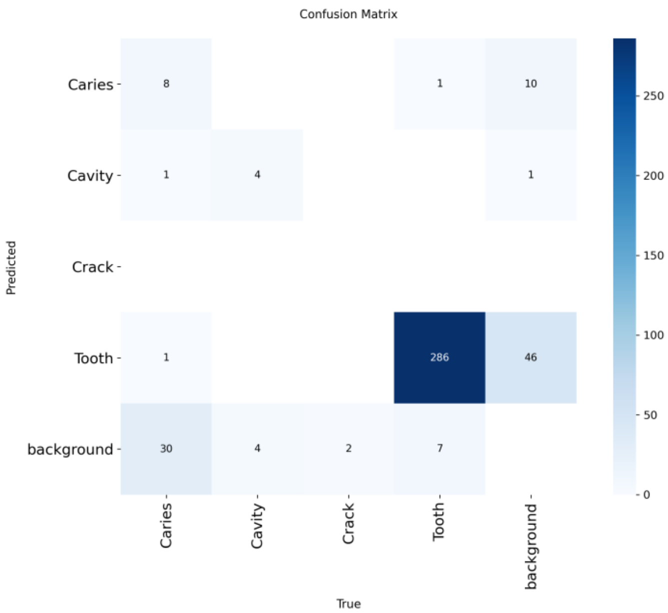


Figure: Performance Evaluation Metrics

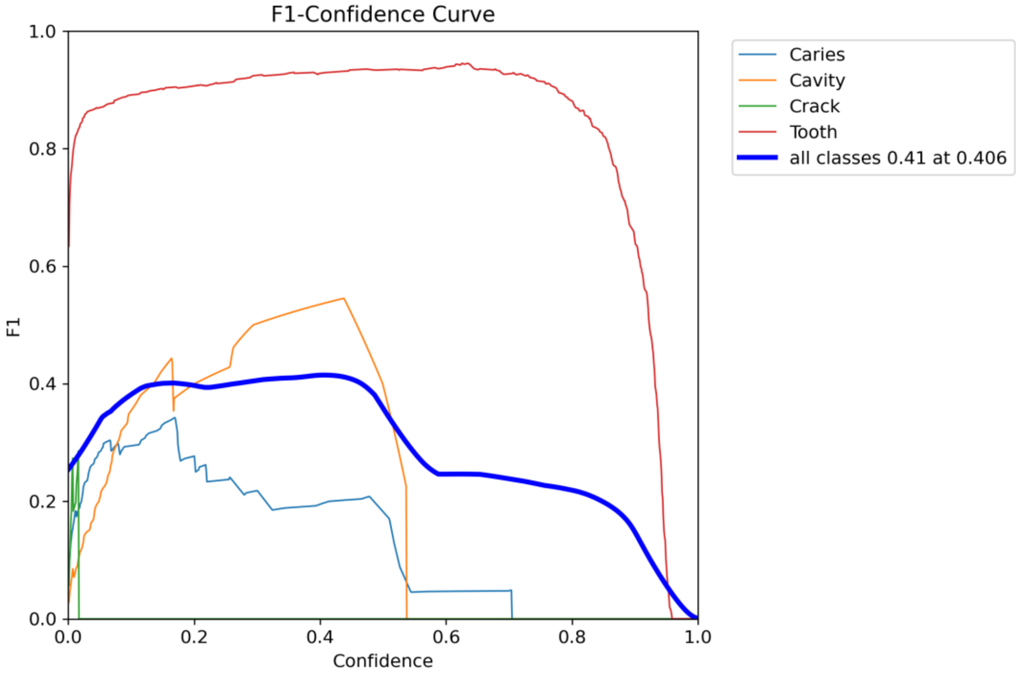


Figure: F1-Confidence Curve

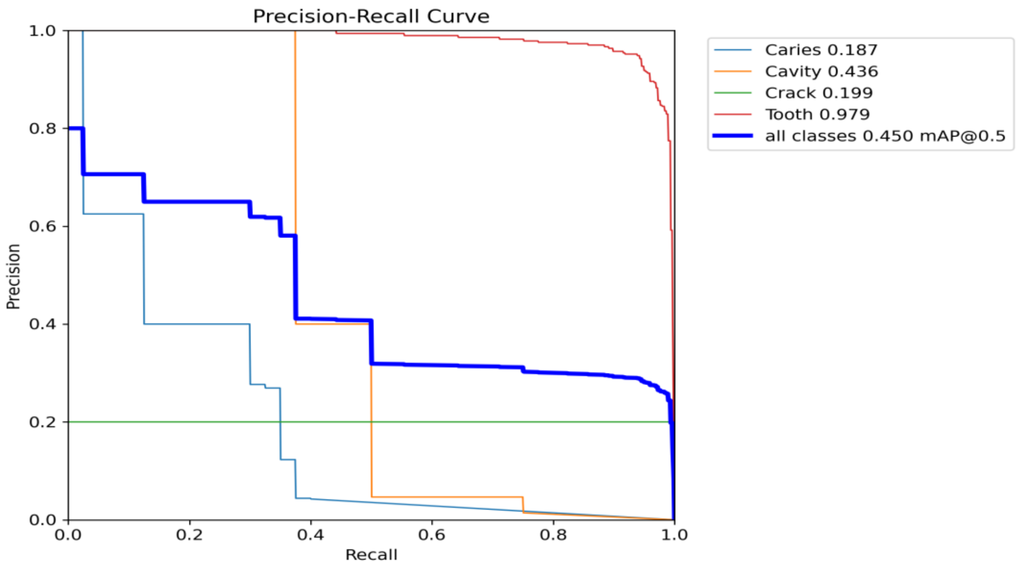


Figure: Precision-Recall (PR) Curve
Figure: Precision-Confidence Curve

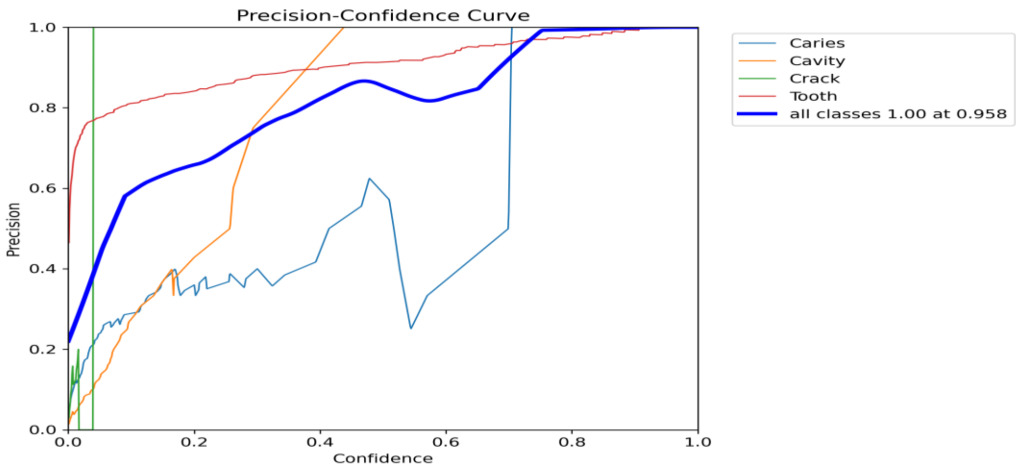


Figure: Precision-Confidence Curve

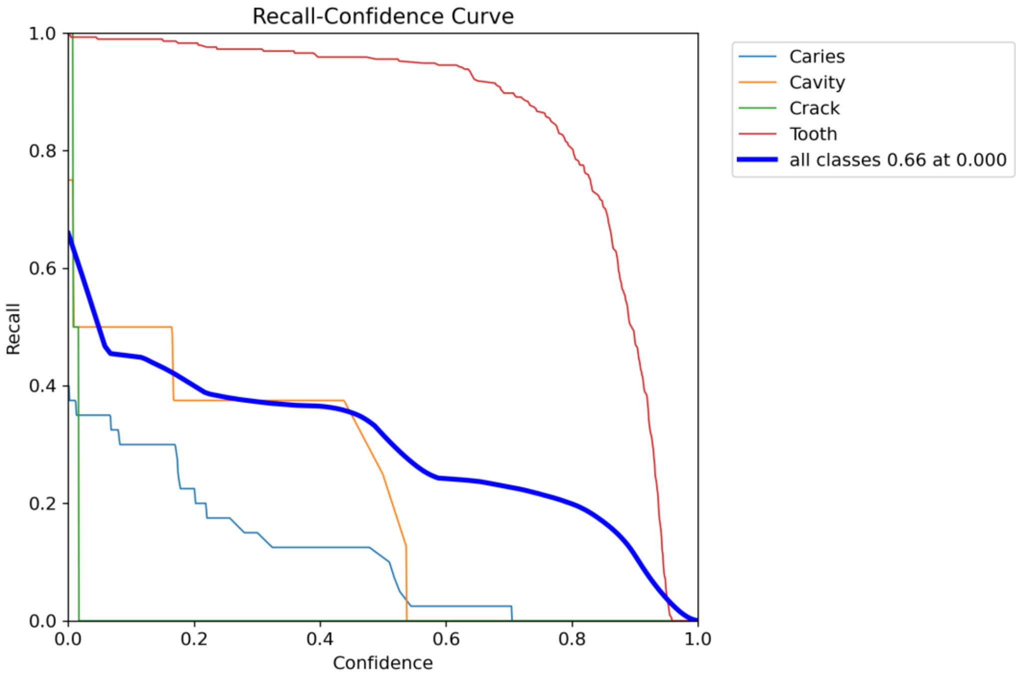
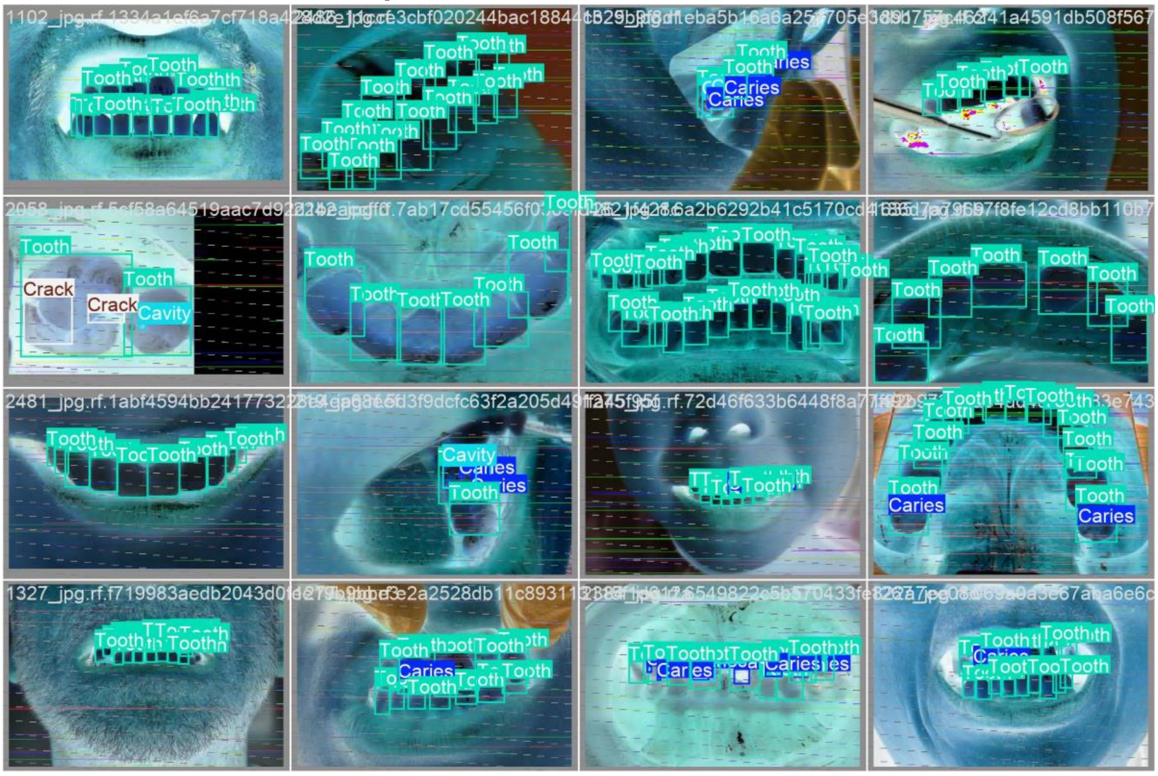


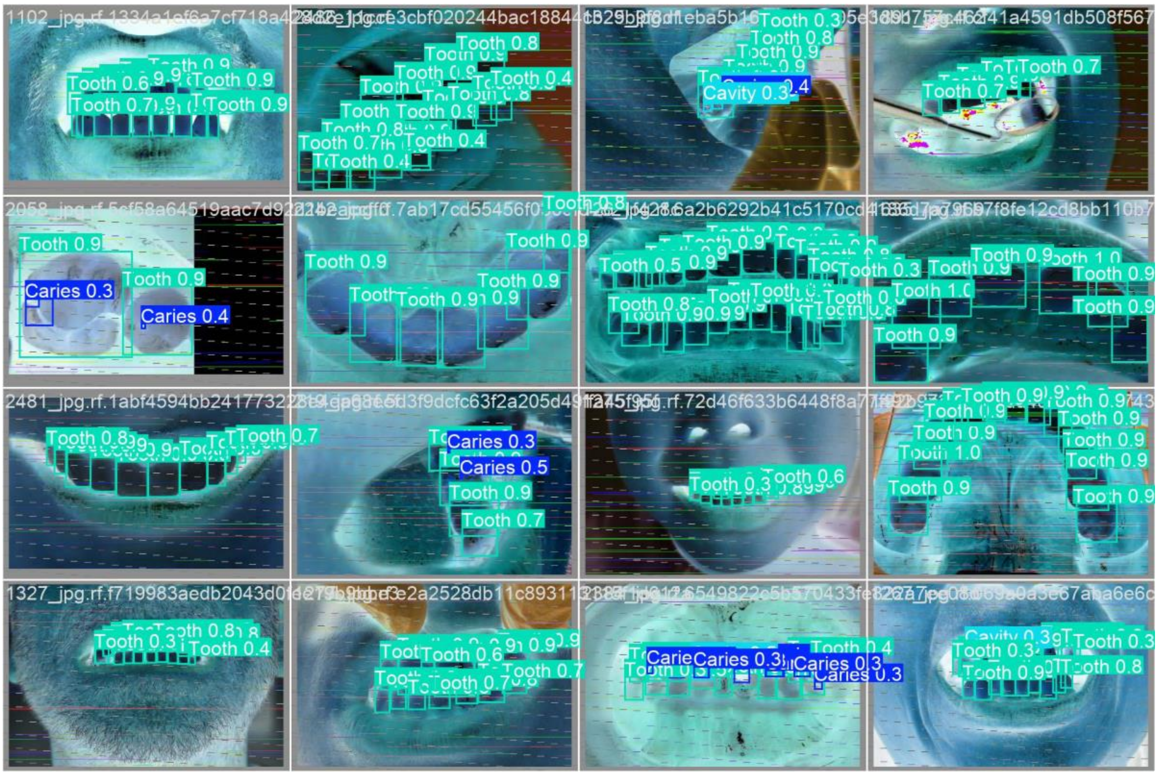
Figure: Recall-Confidence Curve

Model evaluate:

Validation Inference Samples



Visual Sample: Validation Batch 0: Ground Truth



Visual Sample: Validation Batch 0: AI Prediction

Conclusion

The model demonstrates high-fidelity detection, particularly for 'Tooth' and 'Plaque' classes. The visualization of training batches confirms robust data augmentation, while the confusion matrix validates the low cross-class contamination. Future improvements could focus on increasing recall for smaller 'Caries' lesions through higher resolution sampling.

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Future Scope:

The future scope of this project includes:

1. Wireless Connectivity (Bluetooth / Wi-Fi)

The current prototype relies on a wired serial connection, which limits the system's portability and ease of use in real-world settings. Replacing this with Bluetooth or Wi-Fi communication through a dedicated mobile app is justified because:

- Wired connections are impractical in a bathroom environment where water exposure is a safety risk.

- Modern smart devices (smartphones, tablets) are ubiquitous, making app-based control a natural and accessible interface for users.

2.Cloud-Based Database for Brushing History

Storing detection results and brushing sessions locally or not at all is a significant limitation for long-term health monitoring. Adding a cloud database is justified because:

- Longitudinal data (brushing frequency, plaque recurrence zones, session duration) is far more clinically valuable than isolated snapshots.

3.Personalized Oral Health Intelligence

As data accumulates over time, the system can evolve beyond simple detection into a personalized health assistant, which is justified because:

- Machine learning models trained on a user's historical data can predict high-risk zones (areas where plaque consistently reappears) and customize brushing guidance accordingly.