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Measuring Endodontic Working Length Using Artificial Intelligence

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ABSTRACT

The objective of an endodontic treatment is to eliminate infection and inflammation caused by microbes within root canal and the Periapical region of the tooth. This involves cleaning, shaping, disinfecting, and closing the canals to the proper working length. With traditional image processing methods, it is difficult to precisely measure the root canal length. This retrospective clinical study evaluates a self-created dataset of X-ray images of teeth, annotated by medical technicians with defined root canal measurements, was used as input for the system. To measure the endodontic working length the proposed system involvesseveral steps which includes high-resolution dental image acquisition, pre-processing and reducing noise through Gaussian filtering and improving contrast with histogram equalization, Image cropping, Segmentation using Thresholding methods and edge detection with Canny algorithms, Bounding box to get tooth height and calculation of measurement of root canal length by measuring the distance along the skeleton from the entrance to the apex, with curvature analysis algorithms. The results of proposed measurement are validated with review by dental professionals and found that system shows 86.51 % of accuracy. The use of artificial intelligence for root canal measurement significantly advances dental diagnostics. By automating the measurement process, the Artificial Intelligence (AI) system enhances accuracy, efficiency, and reproducibility, ultimately contributing to improved patient outcomes.

1. INTRODUCTION

Dental infections are notoriously painful and commonly affect many individuals. Effective treatment of these severe infections necessitates the elimination of bacteria [1]. Endodontic treatment is a crucial method for addressing these infections and alleviating the associated pain. Success of a root canal treatment depends largely on the accurate determination of endodontic working length. However, determining and maintaining the working length of a root canal system is a very challenging task. Improper working length determination may result in failure of the therapy and the patient may even loose the tooth. Hence, accurate determination of working length is essential to achieve optimal healing and success of the endodontic treatment.

Initially, dental professionals relied solely on tactile sensation and radiographic imaging to estimate the working length. Manual tactile sensation and intraoral imaging are the conventional and most commonly used techniques. Several methods involved using standard radiographs, where dentists would insert files into the canal and take X-rays to visualize the position of the file tip relative to the root apex [2].The introduction of electronic apex locators (EAL) in the 1960s marked a significant advancement in endodontic measurement technology. These devices improved accuracy by measuring the electrical properties of the canal and detecting the transition from periodontal ligament to root canal space [3]. Over the years, EALs have evolved in their precision and usability, becoming a standard tool alongside periapical (PA) radiographs for determining working length in clinical practice [4].

In the late 20th and early 21st centuries, the integration of digital technology in dentistry paved the way for more sophisticated imaging techniques. Cone beam computed tomography (CBCT) emerged as a powerful tool, providing three-dimensional images that offered greater detail and accuracy compared to traditional two-dimensional radiographs [5]. CBCT allowed clinicians to visualize the complex anatomy of root canals more clearly, enhancing the accuracy of working length measurements and diagnosis of periapical pathologies [6].

The advent of AI and machine learning in the mid-2010s revolutionized many fields, including medical imaging and dentistry. AI systems, with their ability to analyze large datasets and identify patterns, presented new opportunities for automating and improving diagnostic processes. In endodontics, researchers began exploring AI applications for various tasks, including the measurement of root canal working length [7]. In AI, Models are trained using datasets. AI models keep improving their predictions with the inclusion of new data [8]. AI can work efficiently with large datasets and even nonlinear relations. Machine learning (ML), a sub-domain of AI, performs very well in the prognosis prediction of dentistry. In dental implantology prognosis, ensemble selection and support vector machine models can predict individual implant average bone levels based on clinical and radio-graphical variables [9]. Several ML models, including random forest (RF), have been exploited to forecast pathologic lymph node metastasisin patients with oral cancer and achieved the best learning performance with an AUC of 0.840 [10]. Treatment options are considerably simplified and made more safe and reliable with such tools.

There is currently no definitive evidence in the literature linking the quantitative evaluation of accuracy of working length estimation and the effectiveness of procedures. While several studies have examined the impact of various factors, including canal curvature and preoperative working length estimation, on preoperative outcomes, specific experimental investigations into these parameters in root canals on extracted teeth remain limited. This study aimed to address these gaps by firstly investigating how the root canal affects radiographic working length estimation in extracted single-rooted human premolars. Secondly, it aimed to segment image to accurately measure the root canal working length, employing quantitative evaluation through X-ray imaging. The following key contributions from the present study advance the dental diagnostics;

- Enrichment of the process of evaluation by the model with a wide range of root canal cases through creation of exhaustively diverse dental radiograph dataset.
- Improved visibility of dental images through addressing the issues related to inconsistent illumination and contrast by integration of AI techniques.
- Improvement in detection and measurement of working length of root canal using precise segmentation.

The article begins with an introduction to the research domain, followed by literature review, detailed contributions including a diverse dataset, image enhancement, segmentation model and working length measurement in root canal treatment, concluding with validation of the model's efficacy through analysis of experimental results.

2. LITERATURE REVIEW

Radiographic assessment is essential for accurate measurement of endodontic working length, a critical aspect in diagnosing and treating conditions like apical periodontitis. Various radiographic techniques and scoring systems have been explored by researchers to improve the precision of these measurements. This review examines key studies that have advanced methods such as the periapical index, cone-beam tomography and other innovative approaches, aiming to enhance the reliability of determining the root canal's correct length in dental procedures.

Tsukuda, T et al. [11] investigated the use of three-dimensional spatial reproduction with stereoscopic vision for the purpose of estimating the length of root canals. Within the scope of this research, a unique approach to dental imaging is presented, which makes use of sophisticated three-dimensional techniques to improve the precision of root canal measurements. When compared to more conventional two-dimensional approaches, the research reveals that stereoscopic vision yields superior precise findings. The results of this study indicate that this technology has a substantial potential for use in endodontic operations, as it can provide a more trustworthy and comprehensive evaluation of root canal structures. It is important to emphasise the significance of novel imaging techniques in clinical practice since this innovation has the potential to lead to improved diagnostic and treatment outcomes in the field of dental care.

Van Pham, K et al. [12] examined the accuracy and agreement of three different types of endodontic length measurement software, viz. 3D Endo software, standard CBCT software, Romexis Viewer at three different voxel sizes and the EAL ProPexPixi. The research covered 329 root canals in 120 removed human molars. The root canal lengths of the teeth were measured using Romexis Viewer, 3D Endo's suggested length (3D-PL), and corrected length (3D-CL). A CBCT scan was performed on the teeth at voxel sizes of 0.075, 0.10, and 0.15 millimetres. The degree to which the methodologies agreed with the AL measurements was evaluated by the use of statistical analyses such as Fisher's exact test, paired t-test, and Bland–Altman plots. With an accuracy of ±0.5 mm, the ProPexPixi performed really well. On the other hand, Romexis Viewer data were consistent across all voxel sizes, and the 3D-PL and 3D-CL measures were in agreement with AL at voxel sizes of 0.15 mm and 0.10 mm, respectively. Nevertheless, neither the conventional computed tomography (CBCT) measurements performed using Romexis Viewer nor the customised software were able to reach a precision of one hundred percent within a range of ±0.5 mm.

Sisli SN et al. [13] utilised CBCT to examine the differences and similarities between two-dimensional (2D) and three-dimensional (3D) techniques for assessing root canal lengths in molar teeth. The study examined the precision of various techniques, drawing attention to the inherent differences that may exist between two-dimensional and three-dimensional measurements. In comparison to the 2D approaches, the findings suggested that the 3D CBCT gave measurements that were more accurate and trustworthy. This study highlights the significance of utilising modern 3D imaging techniques in endodontics to increase the accuracy of root canal length estimations, which will eventually lead to improvements in clinical results and patient care in dental offices.

VermaSimran et al. [14] investigated a variety of techniques for measuring the length of root canals, highlighting the clinical significance of these techniques in endodontics. In this study, conventional radiography methods, EALs and cutting-edge imaging modalities including CBCT are all evaluated and compared. The authors evaluate the benefits and drawbacks of each approach, pointing out that although old methods are in widespread usage, EALs and CBCT provide more accuracy and dependability than traditional methods now available. This study emphasises the significance of accurate canal length measurement for the successful completion of endodontic treatment, and it advocates for the use of cutting-edge technology in order to enhance both diagnostic and therapeutic outcomes.

Pham et al. [15] evaluated the accuracy of root canal length measurements using CBCT at different slice thicknesses, specialized software and EAL compared to AL. The study included 111 extracted human molars with 302 root canals scanned using CBCT equipment with a voxel size of 0.075 millimetres. CBCT software at slice thicknesses of 0.6, 1.2, and 2.4 millimetres and dedicated software for planned or operator-set lengths were used to estimate root canal lengths. Measurements were also taken with EAL and a ruler (AL) post-preparation of the endodontic access cavity. Statistical analysis including paired t-tests and Bland–Altman plots at a significance level of 0.05 revealed that EAL achieved 100% accuracy within ±0.5 mm. CBCT showed significant concordance with EAL data at a 1.2 mm slice thickness ($p = 0.349$), but was less accurate compared to AL, particularly at the thinnest slice thickness. Overall, the study confirmed EAL as a reliable and accurate method for root canal length measurement.

Goel T et al. [16] wanted to determine whether or not standard radiography techniques, radiovisiography (RVG), and apex locators were different in terms of the accuracy of working length measurements in single-rooted permanent teeth. In order to evaluate the working length measurements acquired by each approach, they analysed the data from 202 permanent teeth that were single-rooted. Apex locators demonstrated the highest level of accuracy when compared to conventional radiography and RVG, according to the findings of the study, which indicated that all three modalities exhibited varied degrees of accuracy as well. It is vital to take into consideration these findings when it comes to clinical practice and treatment planning since they provide useful insights into the efficacy of various strategies for evaluating working length in endodontic treatments.

Sima Nikneshan et al. [17] studied several different image processing approaches to determine how they affected the accuracy of endodontic file length measurements. In this study, a variety of techniques for improving the quality of endodontic radiography pictures are investigated, and the preciseness of measuring file lengths is evaluated in relation to these techniques. The study assesses the effectiveness of various methods in precisely calculating the length of endodontic files by means of a comparative analysis conducted by the researchers. The objective of the researchers is to enhance the clarity and resolution of radiography images by employing a variety of image processing techniques, such as contrast enhancement, noise reduction, and edge identification. This will allow for more precise assessments of endodontic file lengths than was previously possible. It is vital to take into consideration the implications of these findings for clinical practice in endodontics since they provide useful insights into the optimisation of image processing techniques for the purpose of improving the accuracy of endodontic measures.

Van Pham et al. [18] used three distinct approaches to explore endodontic length measures in their study, viz. EAL, CBCT and 3D endodontic. The purpose of the study is to assess the precision and dependability of different methods for estimating the length of root canals during endodontic treatments. The study evaluates how well 3D Endo, CBCT and EAL determine endodontic lengths by comparing the measurements produced from each approach with the actual lengths. With painstaking analysis and statistical comparison, the study offers insightful information on how well these strategies work in clinical settings, highlighting both their advantages and disadvantages. The results of this study add to the body of information already available on endodontic length measures and help doctors choose the best approach depending on the particular clinical situation and patient characteristics.

Faraj, B.M et al. [19] examined the effect of root canal curvature as a prognostic factor and examined how it affected the diagnostic accuracy of postoperative canal axis modification and radiographic working length assessment. The study assesses the diagnostic accuracy of postoperative canal axis modification techniques and radiography methods in relation to root canal curvature by an in vitro comparative analysis. Faraj clarifies the relevance of root canal curvature as a factor of diagnostic accuracy and procedural results in endodontic treatments by the use of precise measurements and statistical analysis. The results give insightful information on the intricacies of root canal morphology and its consequences for clinical practice. Endodontic practitioners may use this information to optimise treatment plans that take into account the unique features of the root canal system. This research advances our knowledge of the variables affecting endodontic operation effectiveness, opening the door to better patient outcomes and higher standards of care in dental practices.

Maria Lorena Cardoso et al. [20] provided insight on an important area of paediatric dentistry by concentrating on the in vitro assessment of working length in primary teeth. The goal of the study is to clarify the ideal working length for endodontic operations on primary teeth through the careful execution of experiments and analysis. The authors offer insightful information about the distinct anatomical traits of primary teeth and how they relate to endodontic therapy through meticulous measurements and observations. The results provide important direction for dentists in precisely establishing the working length in paediatric root canal therapy, improving the standard and effectiveness of dental treatment for young patients. This work adds to the corpus of paediatric dental knowledge, supporting evidence-based procedures and enhancing clinical results in the treatment of primary tooth endodontics.

3. METHODOLOGY

A. Dataset Creation

The criteria for selecting tooth images for root canal length measurement were as follows:

i. Each image had to fully display the length of the larger teeth.

ii. The images were chosen based on optimal exposure, contrast, and brightness values, ensuring high-quality X-rays without flaws, strong superimpositions, or other technical issues.

iii. Every selected picture needed to depict at least one root canel finding. Ultimately, 1551 images of periapical lesions with need to perform root canel meeting these criteria were identified and assigned unique identifiers for inclusion in the study.

Figure 1 shows the Dental images from collected data.

Figure 1. Dental images from collected data [21]

B. Proposed Methodology

The process of accurately measuring root canals in dental X-ray images is a critical component of endodontic diagnostics and treatment planning. This task is effectively automated using advanced image processing techniques, which involve several key steps to ensure precision and reliability. Following figure shows the proposed system architecture for Root Canal Measurement Using Image Processing technique.

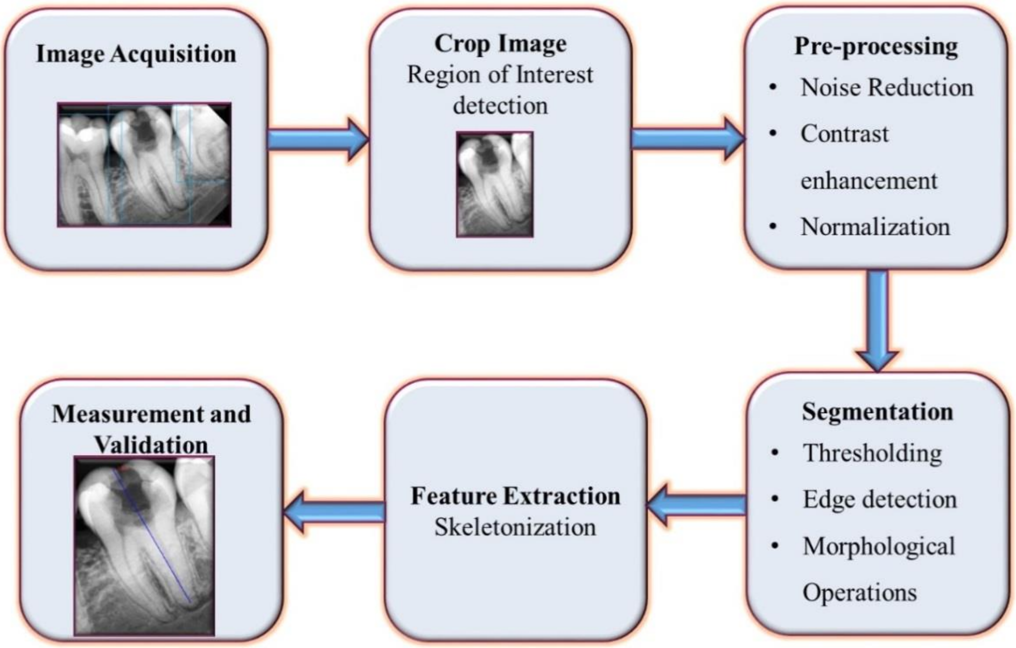

Figure 2. Proposed System Architecture

The system begins with **image acquisition** (Figure 2), where high-resolution dental images are captured using specialized imaging equipment. These images form the raw data input for subsequent processing stages. The initial step in the image processing pipeline is **pre-processing**, which aims to enhance the image quality by reducing noise and improving contrast. Techniques such as Gaussian or median filtering are employed for noise reduction, while histogram equalization can enhance contrast, making the structural details of the tooth more discernible. Following pre-processing, the system performs **segmentation** to isolate the root canal area from the surrounding dental structures. This involves applying thresholding methods to distinguish the tooth from the background and edge detection algorithms like Canny to delineate the canal boundaries. Morphological operations such as dilation and erosion refine these boundaries, ensuring a clear and accurate segmentation. The next phase involves **feature extraction**, where the system identifies and extracts critical features of the root canal, such as its contours and skeletal structure. Contour detection algorithms trace the canal boundaries, while skeletonization reduces the segmented canal to a single-pixel-wide path, facilitating accurate tracing of the canal's length and shape. With the features extracted, the system proceeds to the **measurement** stage. Here, the length of the root canal is calculated by measuring the distance along the skeleton from the canal entrance to the apex. Curvature analysis algorithms assess the shape of the canal, providing essential data on its geometry. To ensure the accuracy of these measurements, a **validation and verification** step is included. This involves a review by dental professionals and a comparison of the automated measurements with manual data, thus verifying the system's reliability. Overall, the use of image processing for root canal measurement represents a significant advancement in dental diagnostics. By automating the measurement process, it enhances accuracy, efficiency, and reproducibility, ultimately contributing to better patient outcomes.

C. Proposed Algorithm

Step 1. Image Acquisition:

Dental X-ray imaging begins with the capture of high-resolution images using specialized dental equipment, such as intraoral or extraoral X-ray machines. Intraoral X-rays are taken inside the mouth to provide detailed views of individual teeth and roots, while extraoral X-rays encompass larger areas like the entire jaw or skull. Integrated with specialized software, these digital images enable dentists and radiologists to analyze and interpret them more efficiently, facilitating precise diagnosis and treatment planning for dental conditions [21].

Step 2. Pre-processing

The initial stage of the image processing workflow involves raw dental images captured using specialized dental imaging equipment, which serve as the input data for subsequent processing. Initially image is **crop** to get single tooth, Figure 3 shows the cropped image of tooth, the image cropping involves, first, load the image and convert it to grayscale. Apply Gaussian blur to remove noise, then use a thresholding method to create a binary image. Detect edges using the Canny edge detection method and refine the tooth shape with morphological operations. Identify the tooth contour using contour detection and compute its bounding box. Finally, use the bounding box coordinates to crop and extract the tooth from the original image.

Initially, noise reduction techniques are applied to mitigate irregularities and pixel-level noise in the images. Filters like **Gaussian filtering** are utilized to achieve smoother textures and cleaner edges, thereby enhancing the overall image quality. The basic principle of Gaussian noise reduction involves applying a Gaussian filter to the image. The filter kernel, often referred to as the Gaussian kernel or Gaussian mask, is a matrix of weighted values cantered around the pixel of interest. The formula for applying a Gaussian filter $G(x, y)$to an image $I(x, y)$can be expressed as:

$$I_{smoothed}(x, y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} G(i, j).I(x+i, y+j) \tag{1}$$

Where

- $I_{smoothed}(x, y)$ is the smoothed image intensity at pixel (x, y)
- $G(i, j)$ is the Gaussian kernel coefficient at position (i, j)
- $I(x + i, y + j)$ is the intensity of the original image at position $(x + i, y + j)$,
- k defines the size of the kernel (typically an odd number, e.g., 3x3, 5x5).

The Gaussian kernel $G(i, j)$is defined as:

$$G(i, j) = \frac{1}{2\pi\sigma^2} e^{-\frac{i^2+j^2}{2\sigma^2}} \tag{2}$$

Where

- σ is the standard deviation of the Gaussian distribution,
- i *and* j are the coordinates relative to the center of the kernel.

Figure 3. (a) Applying Bounding Box to image (b) Crop Image

Salt-and-pepper noise removal is applied after getting cropped image. Salt-and-pepper noise appears as white and black pixels randomly scattered over an image. To remove this type of noise, a median filter is effective because it replaces each pixel's value with the median value of the intensities in the neighbourhood of that pixel, preserving edges while removing noise. Figure 4 shows the de-noised image.

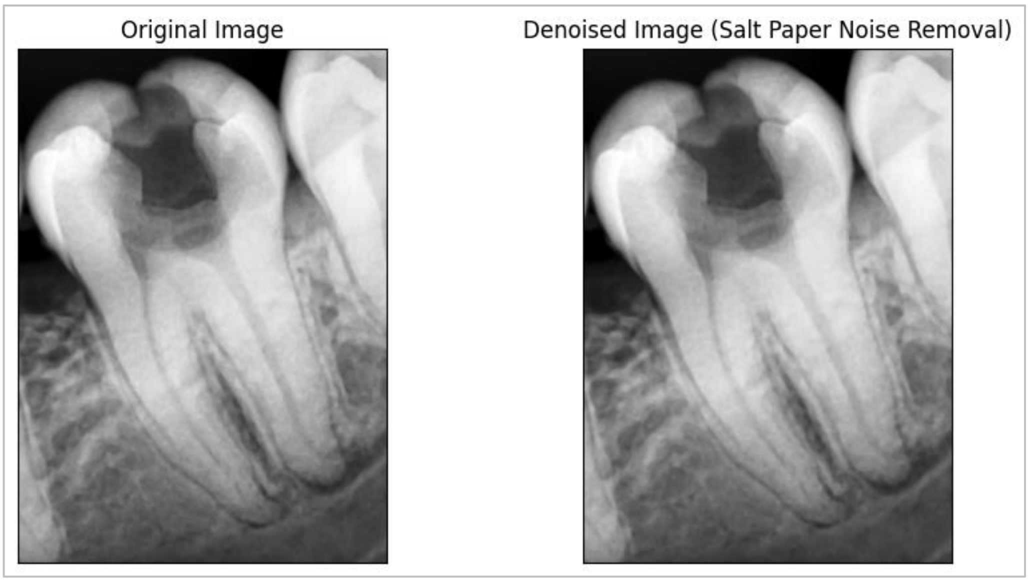

Figure 4. De-noised Image (Salt Paper Noise Removal)

Following noise reduction, **CLACHE** (Contrast Limited Adaptive Histogram Equalization). CLAHE is an advanced version of Adaptive Histogram Equalization (AHE) that improves contrast in images by applying histogram equalization in small regions (tiles) of the image. Unlike AHE, CLAHE prevents over-amplification of noise by limiting the contrast enhancement as depicted in Figure 5. The process involves the following steps;

- *Divide the Image into Tiles:* The image is divided into smaller, non-overlapping regions called tiles.

- *Apply Histogram Equalization:* Perform histogram equalization on each tile independently to enhance contrast locally.
- *Clip the Histogram:* To limit noise amplification, clip the histogram at a predefined value (clip limit). This redistributes the clipped pixels evenly across the histogram.

$$\text{clip limit} = \text{clip factor} \times \frac{\text{number of pixel in tile}}{\text{number of bins}} \tag{3}$$

- *Interpolate Between Tiles:* To avoid artificial boundaries between tiles, bilinear interpolation is used to combine the results of adjacent tiles.

Additionally, normalization processes are implemented to standardize brightness and contrast levels across all images. This ensures uniformity in image quality, making the enhanced images more suitable for consistent and reliable analysis by dental professionals.

Figure 5. CLACHE Enhance Image

After CLACHE, **Canny Edge Segmentation** is applied, Canny edge detection is a multi-stage algorithm that aims to identify edges in an image as accurately as possible while minimizing noise and false detections. The Gradient Calculation is applied to pre-process (CLACHE Enhance Image); this helps in identifying regions of high spatial frequency, which correspond to edges and to obtain thin edges, non-maximum suppression is applied. This step retains only the local maxima in the direction of the gradient. After Gradient calculation, Double Thresholding step is applied to classify pixels as strong, weak, or non-edges based on their gradient magnitudes. The final step is to track edges by suppressing all weak edges that are not connected to strong edges, ensuring continuity. Figure 6 shows the Canny Edge Segmented Image.

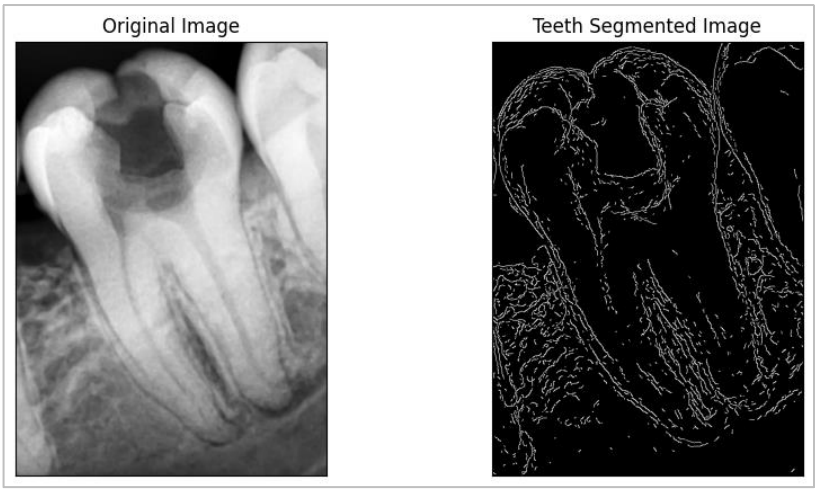

Figure 6. Canny Edge Segmented Image

After image segmentation the next goal is to **find counters**. The primary goal of Finding Contours, is to identify and extract contours from a binary image, where contours represent continuous curves that delineate the boundaries of objects or regions of interest. Once contours are identified using the next step is to visualize them on the original image which is shown in figure 7 (a) while figure 7 (b) shows bounding box of height from apex to end of tooth. After getting height

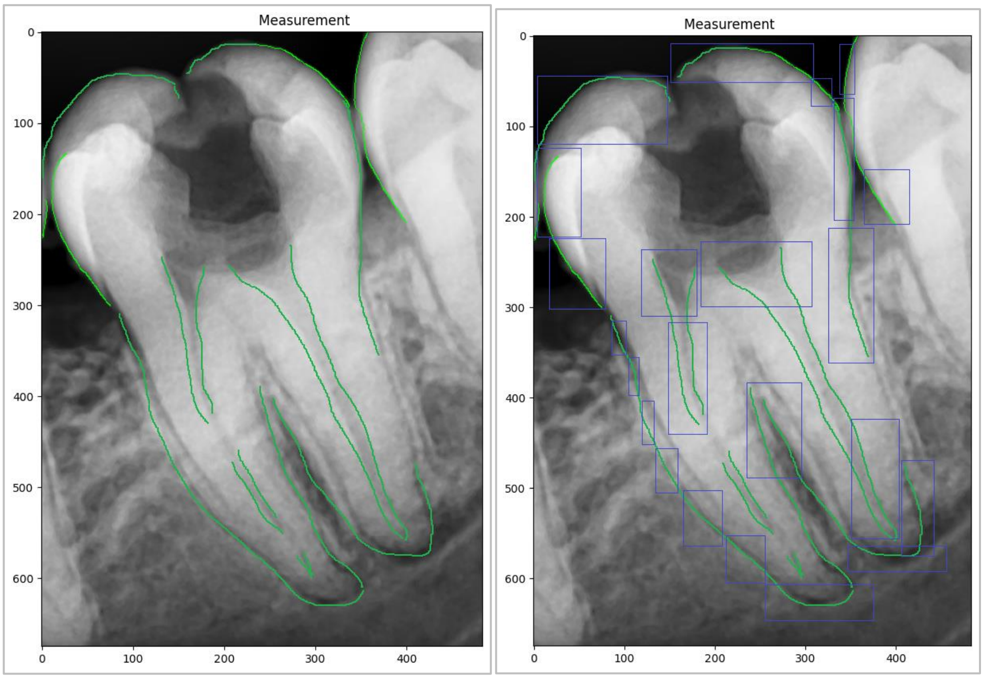

Figure 7. (a) Finding counters (b) Bounding Box for Height Measurement

To determine the **working length of a root canal** from dental imaging, a line is drawn between identified apex and start coordinates using computer vision techniques. This line, typically represented in Blue on the image, is drawn using OpenCV, a library for image processing in Python. The Euclidean distance formula is then applied to calculate the straight-line distance between these coordinates. This distance, expressed in pixels, provides a precise measurement of the root canal's working length, crucial for accurate dental procedures and treatment planning. The Euclidean distance between two points(x_1, y_1) and (x_2, y_2) in a two-dimensional space is calculated using the following formula;

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{4}$$

With the above Euclidian distance, we got the working length of root canal as 17.9 mm which is shown in Figure 8 in blue colour.

Figure 8. Working root canal length measurement

For experimentation, 1551 images are used and result of the output is averaged to get the final accuracy score. The images having root canal curvature show less accuracy compared to that of regular root canal process. The Results are verified with the help of expert reviews, the **validation** ensures that the measurements are correct, reliable, and fit for their intended purpose. The expert reviews are considered, the predicted root canal measurement length is review by domain experts (e.g., dental professionals) who assess the measurements based on their knowledge and experience. After comparing the measurements with ground truth data the accuracy is calculated.

Overall, the process begins with image acquisition, followed by systematic noise reduction, and normalization with bounding box to get single tooth are applied in the pre-processing stage. This prepares the raw dental images by enhancing their clarity and diagnostic quality. Subsequently, segmentation techniques isolate specific features such as root canals, enabling precise measurement and feature extraction. In measuring the working length of root canals, a line is drawn between identified apex and start coordinates using computer vision techniques. The Euclidean distance formula quantifies this straight-line distance, critical for treatment planning in dentistry. Validation and verification ensure accuracy, comparing automated measurements with manual or ground truth data to uphold reliability and clinical relevance. This structured image processing pipeline enhances diagnostic accuracy and supports effective treatment decisions in dental practice.

4. RESULT AND DISCUSSION

A. Performance Parameters

To evaluate the performance of the image processing system for root canal measurement, several key parameters can be considered. These parameters help compare the system's results with ground truth data or manual measurements. Here are some essential performance parameters, along with their formulas:

Accuracy

Accuracy measures the degree of closeness of the measurements to the true value. It can be calculated using the following formula;

$$\text{Accuracy} = \left(1 - \frac{|\text{Measured Length - True Length}|}{\text{True Length}}\right) \times 100\% \tag{5}$$

Dice Coefficient (Dice Similarity Index)

The Dice Coefficient measures the overlap between the segmented root canal and the ground truth. It is calculated as;

$$\text{Dice Coefficient} = \frac{2 \times |A \cap B|}{|A| + |B|} \tag{6}$$

Where,

A is the set of pixels in the segmented root canal.

B is the set of pixels in the ground truth.

B. Technologies and Tools

Table 1. Tools and Technologies used

Parameters	Specification
Tool	Google Colab
Programming Languages	Python
Image Processing Libraries	OpenCV
Machine Learning	TensorFlow, PyTorch(for segmentation)

C. **Result Analysis**

For the experiments, 1551 sample images were taken from practicing endodontists using EasyDent software as input. These images were available in two formats; .bmp and .PNG. The .bmp image is the original image with a pixel ratio of 186 × 135, while the .PNG image is an improved quality image with a pixel ratio of 934 × 676, which is 5 times the resolution of the original image. For better results, the .PNG images were used. When measuring the length in pixel format, the pixel length was divided by 5 and then converted that output into millimetres using the ratio 1 pixel = 0.1 mm.

The conversion equations being used are;

1. Convert the measurement in .PNG pixels to .bmp pixels;

$$\text{length}_{\text{bmp}} = \frac{\text{length}_{\text{PNG}}}{5} \tag{7}$$

2. Convert the measurement in .bmp pixels to millimetres;

$$\text{length}_{\text{mm}} = \text{length}_{\text{bmp}} \times 0.1 \tag{8}$$

3. Combining these steps into a single equation;

$$\text{length}_{\text{mm}} = \frac{\text{length}_{\text{PNG}}}{5} \times 0.1 \tag{9}$$

Figure 9 shows the final outcome of predicted length measurement for root canal along with original input image and ground truth, the accuracy is calculated using Equation (5). For example, for sample tooth 1, the ground truth length is of 18.5 mm (expert review) while the predicted measured length is of 17.9 mm. Putting these values in Equation (5);

$$\text{Accuracy Teeth 1} = \left(1 - \frac{|18.5 - 17.9|}{17.9}\right) \times 100 = 96.64\% \tag{10}$$

In the similar fashion, the accuracy for the remaining samples is determined and presented in Table 2.

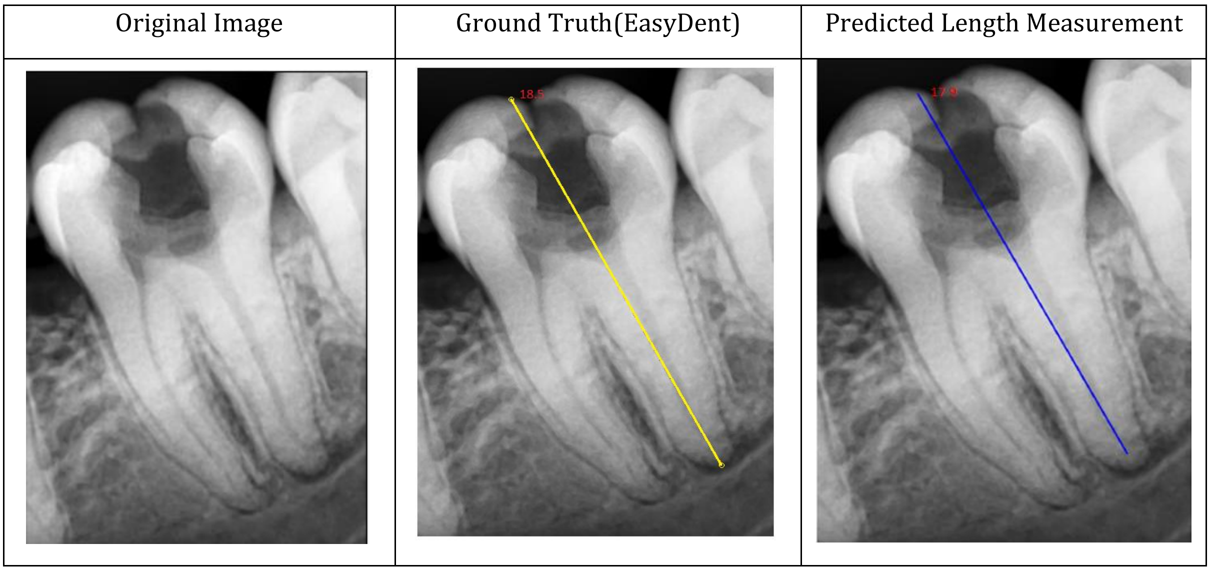

Figure 9. (a) Original Tooth Image (b) Ground Truth (c) Predicted Length Measurement

Table 2: Comparison between True Length and Measured Length by Present Model

Sample Images	**True length by Expert (EasyDent) in mm**	**Measured length by Our Model in mm**	**Accuracy in %**
Image 1	18.5	17.9	96.65
Image 2	22.5	21.6	95.83
Image 3	15.8	14.9	93.96
Image 4	23	21.8	94.50
Image 5	18.7	18.1	96.69
Image 6	16.1	15.9	98.74
Image 7	17.1	16.3	95.09
Image 8	19.5	18.9	96.83
Image 9	16.5	16	96.88
Image 10	20.5	19.9	96.98

With the proposed system integrating systematic image acquisition, noise reduction, contrast enhancement, normalization, segmentation for feature isolation and accurate measurement techniques, an average accuracy achieved for given 10 images is 96.21% and overall average of all 1551 tested sample images is 86.51%. This outcome underscores the effectiveness of the image processing pipeline in enhancing diagnostic clarity and precision in dental practice. Validation and verification processes further bolster confidence by comparing automated measurements with manual or ground truth data, ensuring robustness and reliability. The systematic approach not only optimizes the quality of dental images but also supports clinicians in making informed treatment decisions, highlighting its significance in modern dental diagnostics.

5. CONCLUSION

The study focuses on detecting the measurement of the root canal, essential for precise endodontic treatment aimed at eliminating microbial infection and inflammation in the root canal and periapical region. In this retrospective clinical study, a curated dataset of X-ray images annotated with defined root canal measurements was utilized to evaluate a novel system. The proposed approach integrates high-resolution image acquisition, noise reduction with Gaussian filtering, contrast enhancement via histogram equalization, image cropping, segmentation using Thresholding and edge detection, and precise measurement of root canal length using Euclidian distance is calculated. Validation by dental professionals confirmed an accuracy of 86.51%, underscoring the reliability and effectiveness of the system. By leveraging artificial intelligence, this system enhances diagnostic precision, efficiency, and reproducibility, empowering clinicians with reliable data for informed treatment decisions in modern dental practice.

Furthermore, advancements in endodontic instruments, such as flexible and curved files, can be developed to better navigate and adapt to the natural curvature of the root canals, thereby improving the efficacy and safety of the treatment.

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