Research Paper

Performance Analysis of Modified Enhancement Method for Dental Images - Towards the Effective Detection of Dental Disorders

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Abstract: Dental health maintenance is essential for overall physiological well-being, and X-ray imaging remains a fundamental diagnostic tool for comprehensive dental examination. While direct clinical observation by dentists is primary, computer-aided diagnostic tools serve as valuable secondary readers, enhancing diagnostic accuracy and efficiency. This study proposes and evaluates the Gaussian CLAHE Enhancement (GCE) method, which combines Gaussian filtering (GF) with Contrast Limited Adaptive Histogram Equalization (CLAHE) for dental radiograph enhancement. The proposed GCE method demonstrates superior performance in improving dental image clarity while maintaining low computational complexity. Comparative analysis against existing dental image enhancement techniques reveals significant improvements across multiple quantitative metrics: Mean Squared Error (MSE), Peak Signal-to-Noise Ratio (PSNR), Contrast Ratio (CR), Structural Similarity Index (SSIM), and Lightness Order Error (LOE). The GCE method achieves an MSE of 0.24, PSNR of 39.351 dB, and enhancement accuracy of 95.83%, representing improvements of 2.61% over the dFDB-LSHADE method, 6.95% over the Ded-Net method, and substantial gains over other state-of-the-art techniques. These results demonstrate the clinical viability of the proposed method as a reliable computer-aided diagnostic tool for dental radiograph enhancement, with potential applications in automated dental diagnosis and treatment planning.

Keywords: Dental Radiography, Image Enhancement, Gaussian Filtering, CLAHE, Computer-Aided Diagnosis, X-ray Image Processing, PSNR, SSIM

Introduction

Oral health encompasses the maintenance of teeth, gums, and tongue, with dental health playing a pivotal role in overall systemic well-being. Robust dental health is associated with numerous physiological benefits, including reduced cardiovascular risk, lower incidence of diabetes, enhanced pulmonary function, decreased cancer susceptibility, improved fertility outcomes, elimination of halitosis, optimized digestion, facilitated weight management, and overall longevity. However, contemporary dietary patterns and environmental factors have significantly compromised dental health globally, necessitating consistent monitoring, preventive care, and professional intervention.

Dental radiography serves as an indispensable diagnostic tool for comprehensive oral examination. To ensure patient safety, modern radiographic protocols employ minimal radiation exposure, which consequently may compromise image quality and diagnostic clarity. This inherent trade-off between radiation safety and image quality creates a critical need for advanced image enhancement techniques to facilitate accurate disease detection and diagnosis. Enhanced radiographic images enable clinicians to make informed diagnostic decisions and develop appropriate treatment strategies.

Significant research efforts have been directed toward developing image processing techniques for dental radiograph enhancement. Ahmad et al. (2010)

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pioneered the application of sharp contrast-limited adaptive histogram equalization (SCLAHE) for dental disease detection. Choi (2011) examined the economic and temporal efficiency of various detection methods, highlighting the clinical utility of panoramic radiography. Subsequent comparative studies by Ahmad et al. (2012) evaluated the diagnostic performance of multiple CLAHE variants.

Mathematical modeling approaches have demonstrated promise in automated detection systems. Naebi et al. (2016) developed mathematical models for dental caries and restoration detection in digital radiographs, achieving an 8% error rate with robust convergence properties. Preprocessing techniques combining Gaussian filtering and histogram equalization (HE) were investigated by Radhiyah et al. (2016), yielding improved PSNR values and enhanced image quality.

Comprehensive reviews of dental imaging modalities, anatomical structures, and prevalent pathologies have been provided by Solanki and Mahant (2017) and Geetha and Sunitha (2017), who systematically evaluated preprocessing methods for image segmentation and disease detection. Salim et al. (2017) quantified enhancement performance using MSE, PSNR, and maximum error metrics for low-contrast dental radiographs. Qassim (2019) demonstrated the efficacy of HE, logarithmic transformation, gamma correction, and CLAHE for periapical image enhancement in dental disorder detection.

Advanced optimization algorithms have been explored for contrast enhancement. Kamoona and Patra (2019) implemented a cuckoo search algorithm for grayscale dental image enhancement, while Simu and Naik (2020) compared three enhancement algorithms, identifying the Artificial Bee Colony (ABC) optimization algorithm as superior based on MSE, PSNR, and SSIM metrics. Virupaiaha and Sathyanarayana (2020) proposed a preprocessing pipeline integrating Gaussian low-pass filtering in the frequency domain with support vector machine (SVM)-based feature extraction, demonstrating effective detection of dental abnormalities.

Hybrid approaches combining multiple enhancement techniques have shown promise. Gazal et al. (2020) evaluated lifting wavelet transform (LWT)-CLAHE integration for detail-preserving enhancement with reduced noise amplification. Vijayalakshmi et al. (2020) conducted a comprehensive literature review of contrast enhancement techniques, emphasizing entropy preservation, brightness maintenance, and structural information retention. Özturk et al. (2020) analyzed ABC algorithm applications across enhancement, segmentation, and classification tasks.

Recent investigations have focused on noise reduction and anatomical structure preservation. Majanga and Viriri (2021) validated Gaussian filtering for noise suppression, while Román et al. (2021) developed methods for anatomical structure evaluation incorporating edge preservation, contrast improvement, and noise reduction. Abdallah et al. (2021) examined denoising techniques coupled with dental structure detection capabilities. Shashikala and Thangadurai (2021) compared dental X-ray and Cone-Beam Computed Tomography (CBCT) images, confirming CLAHE's superior PSNR performance.

Contemporary research has explored deep learning and machine learning paradigms. Altukroni et al. (2023) investigated panoramic and periapical radiographs using advanced computational techniques. Çelik et al. (2024) emphasized super-resolution methods for detection accuracy improvement. Khan et al. (2023) proposed an expert system (Ded-Net) for dental image enhancement and disorder detection, though limitations in capturing high-quality images due to non-uniform illumination and low contrast constrained overall accuracy. Tang et al. (2025) advanced medical image segmentation efficiency, while Yildirim et al. (2025) demonstrated promising results using the dFDB-LSHADE optimization algorithm.

Despite substantial progress, diagnostic accuracy remains the principal challenge in dental image enhancement. This study proposes a novel Gaussian CLAHE Enhancement (GCE) method combining Gaussian filtering with CLAHE to address current limitations and provide enhanced decision support for clinicians. The following sections detail the methodology, experimental validation, and comparative performance analysis of the proposed approach.

Materials and Methods

High visibility medical images with modern devices and with high quality are tough task and processing those high-quality digital images reduces the contrast and the clarity of visual quality. Further, measuring the performance of smart and autonomous systems and finalizing the early detection and diagnosis of oral and dental diseases is also tough. Hence, highest care must be

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taken while forming the enhancement methods for dental images.

One such method is the combination of Noise removal and contrast enhancement. Random motion and the fluctuations of number of photons reaching the detector form various points are called quantum mottle or quantum noise. It is an artifact which is very common in radiography and especially in x-ray imaging. The artifacts produced because of influence of quantum mottle are the main noise in teeth images. Reducing this is the main research task now days. Among the all the existing methods studied the Gaussian filter performs well in dental images because this method reduces the noise by keeping the image details as such.

Since image details are available in the low frequency band, this noise reduction algorithm works good in teeth image. Similar to the noise handling algorithm, a better contrast enhancement algorithm Sharp CLAHE (SCLAHE) has also been used for contrast enhancement. SCLAHE algorithm simply flattens the histogram with higher entropy level. This nature of CLAHE rearranged the intensity level of local regions and works well in low contrast images like teeth x-ray images. It also provides higher entropy compared to all other histogram equalization methods for image enhancement. SCLAHE splits the input image into tiles, computes the histogram, equalize the histogram, bilinear interpolation (computation of clip limit and limiting the contrast with the help of computed clip limit).

SCLAHE has been tested in dental X – ray images and comparison has been done for original and processed images. Further, no preprocessing method has been tested by combining the Gaussian filter for noise removal in frontend (before SCLAHE), backend (after SCLAHE) and SCLAHE for contrast enhancement. And this new combination has been named as Gaussian and CLAHE Enhancement (GCE) filter and tested with many dental images.

The proposed GCE filtering algorithm works well on teeth images in reducing the quantum noise, preserving the edge, high frequency components and texture part of image with remarkable accuracy. The results found has been good in terms of performance measures done and has been shown in the following section.

Process Flow of Proposed GCE Method

Step 1: Input the original Dental image

Step 2: Perform the noise removal by using Gaussian filter

Step 3: Apply Bicubic edge directed interpolation (provides high accuracy with satisfactory time consumption. It also works with 16-pixel (4x4) concept and preserve image quality, maintains image consistency for the enhancement of visual appearance)

3.1: Perform the grid selection based on the point in which it needs interpolation

3.2: Calculation of cubic polynomials to fix the pixel values in the selected grid

3.3: Estimation of pixel intensity values at the required area

Step 4: Apply Gaussian filter again for ensuring noise removal (artifacts if any) and edge sharpening and preservation

Step 5: Preprocessed/Enhanced Dental Image Output.

The following parameters in Table 1 has been found and analyzed for various dental image samples.

Contrast ratio can be found by finding the difference between highest and lowest intensity value of the image, The intensity values can be calculated from the respective histogram. Contrast Ratio of Various Enhancement methods have also been tested.

(a) Original Image S1 (b) GCE Enhanced Image of S1

Fig. 1. Input and Output of Sample Image S1

(a) Original Image S2 (b) GCE Enhanced Image of S2

Fig. 2. Input and Output of Sample Image S2

(a) Original Image S3 (b) GCE Enhanced Image of S3

Fig. 3. Input and Output of Sample Image S3

Table 1. Expressions for Performance Measurement.

Parameter	Mathematical Expression
Mean Squared Error (MSE)	$\mathrm{MSE} = \frac{1}{n}\sum(\mathrm{Yi}-\mathrm{Pi})^2$ Y_i – Estimated value of pixels from an image P_i – Predicted value of pixels from an image n – number of sample pixels of an image
Peak Signal to Noise Ratio (PSNR)	$\mathbf{PSNR} = \mathbf{20log_{10}}\left(\frac{\mathbf{MAX_I}}{\sqrt{\mathbf{MSE}}}\right)$ MAX_I - Maximum possible pixel value of the image
Structural Similarity Index (SSIM)	$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$ μ_x - pixel sample mean of x μ_y - pixel sample mean of y σ_x^2 - Sample variance of x σ_y^2 - Sample variance of y σ_{xy} - Sample covariance of x and y $C_1 = (K_1L)^2$, $C_2 = (K_2L)^2$ the two variables to stabilize the division L – the dynamic range of pixel value ($2^{\text{no.of bits per pixel}} - 1$) $K_1 = 0.01$ and $K_2 = 0.03$ by default
Lightness Order Error (LOE)	$\mathrm{LOE} = (1/m) * \sum(\sum(U(L(x),L(y)) \bigoplus U(L_e(x),L_e(y))))$ m – Total number of pixels in the image L(x) – Lightness value of the pixel x in the original image L(y) – Lightness value of the pixel y in the original image $L_e(x)$ – Lightness value of the pixel x in the enhanced image $L_e(y)$ – Lightness value of the pixel y in the enhanced image $U(s,t) = 1$ if $s \geq t$ $U(s,t) = 0$ if $s < t$ $\oplus$ - if one different valued input, if zero similar valued inputs Double $\sum$ - represents the summing of all x,y pair pixels of the image

Table 2. Comparison of Various Enhancement Methods for Sample Image S1.

Methods	Parameters for Performance Measurement					
	MSE	**PSNR**	**SSIM**	**LOE**	**CT (s)**	**CR**
MF	0.74	21.0562	0.7852	149	2.1	3.4:1
GF	0.76	20.4780	0.7954	146	2.3	3.7:1
CLAHE	0.56	16.8570	0.7984	765	2.9	3.6:1
SCLAHE	0.43	25.2402	0.8941	241	2.4	3.5:1
LWT + CLACHE	0.31	30.2062	0.8943	845	3.1	4.1:1
Ded – Net	0.32	29.4181	0.9368	1667	2.6	4.5:1
dFDB-LSHADE	0.25	38.5831	0.9236	154	4.4	4.7:1
Proposed Method	**0.24**	**39.3514**	**0.9436**	**097**	**4.2**	**5.2:1**

Table 3. Comparison of Various Enhancement Methods for Sample Image S2.

Methods	Parameters for Performance Measurement					
	MSE	**PSNR**	**SSIM**	**LOE**	**CT (s)**	**CR**
MF	0.78	16.1322	0.7765	152	2.3	3.2:1
GF	0.71	22.2143	0.8224	159	2.4	3.5:1
CLAHE	0.52	17.2413	0.7895	842	2.7	3.5:1
SCLAHE	0.47	24.7485	0.8543	278	2.7	3.5:1
LWT + CLACHE	0.33	29.1031	0.8954	1102	3.5	4.3:1
Ded – Net	0.34	28.2316	0.9354	1712	2.6	4.5:1
dFDB-LSHADE	0.30	33.2316	0.9292	213	5.1	4.6:1
Proposed Method	**0.29**	**34.3271**	**0.9392**	**171**	**4.8**	**5.3:1**

Table 4. Comparison of Various Enhancement Methods for Sample Image S3.

Methods	Parameters for Performance Measurement					
	MSE	**PSNR**	**SSIM**	**LOE**	**CT (s)**	**CR**
MF	0.81	14.0025	0.7185	171	2.1	3.2:1
GF	0.69	23.7984	0.8413	140	2.1	3.7:1
CLAHE	0.51	17.3268	0.7135	784	2.7	3.3:1
SCLAHE	0.42	25.7371	0.8853	311	2.2	3.6:1
LWT + CLACHE	0.37	27.4998	0.9021	987	3.4	4.1:1
Ded – Net	0.32	29.4181	0.9317	1597	2.7	4.4:1
dFDB-LSHADE	0.28	35.8271	0.9317	293	4.8	4.8:1
Proposed Method	**0.27**	**37.7423**	**0.9411**	**152**	**4.5**	**5.5:1**

Results and Discussion

Sample images have been referred from Kaggle dataset for dental images. 120 samples have been tested with all the enhancement methods and found satisfactory results. The results for three samples S1 (17), S2 (106) and S3 (591) have been discussed and given in Fig. 1, Fig. 2 and Fig. 3. First image is input and second one is proposed GCE output in all the three cases. Median Filter (MF), Gaussian Filter (GF), CLAHE, SCLAHE, Lifting Wavelet Transform with CLAHE (LWT+CLAHE), Ded-Net and dFDB-LSHADE enhancement methods have been tested along with the proposed GCE method. The output images after the proposed enhancement method is clearer than all other outputs. The parameters measured for comparison and performance evaluation of three sample images S1, S2 and S3 has been given in Table 2 3 and 4 respectively.

The MSE, PSNR, SSIM, LOE and CR are the important parameters for evaluating any such enhancement methods. Less MSE with high PSNR is the main objective of all methods. Further, the image quality can also be assessed by additional parameters like SSIM, LOE, CR and CT. If any enhancement method is able to produce all the parameters in the satisfactory level, then that will be most suitable method for dental image segmentation. Out of 120 sample images tested, the proposed method has produced good results in satisfying all the table parameters. The results of only three images have been tabulated in Table 2, 3 and 4.

Table 2 consists of parameter details for various image enhancement methods utilized for dental image processing of sample image S1, table 3 consists of parameter details for various image enhancement methods utilized for dental image processing of sample image S2 and table 4 consists of parameter details for various image enhancement methods utilized for dental image processing of sample image S3.

Table value shows that the proposed GCE method have produced good results than all other existing dental image enhancement methods. Fig. 4, Fig. 5 and Fig. 6 are given with the comparison details of all the enhancement methods tested for sample image S1 for MSE, PSNR and SSIM.

The proposed GCE method have achieved low MSE of 0.24, higher PSNR of 39.3514 with SSIM value of 0.9436 which is very much improved result compared to all other existing methods tested. Further, the overall accuracy in producing good quality dental images from the total samples taken has been tabulated in Table 5.

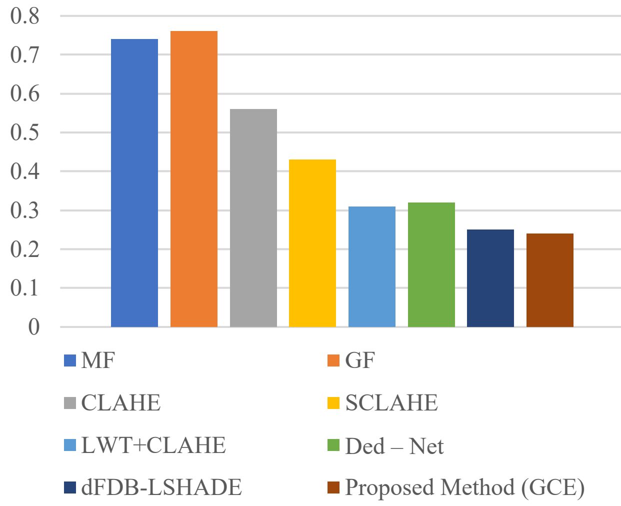

Fig. 4. MSE of Sample Image S1 for all the Methods Tested

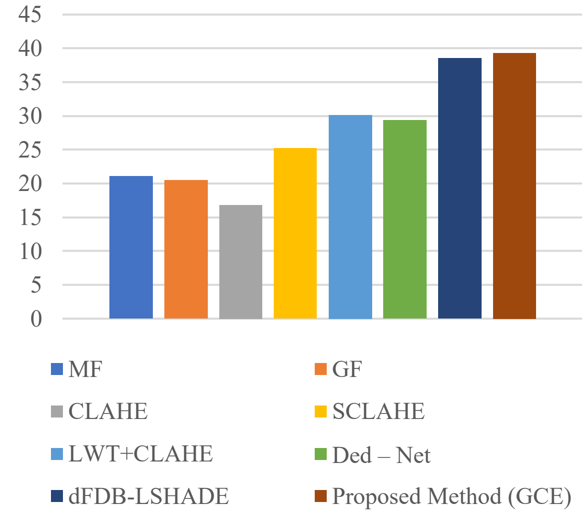

Fig. 5. PSNR of Sample Image S1 for all the Methods Tested

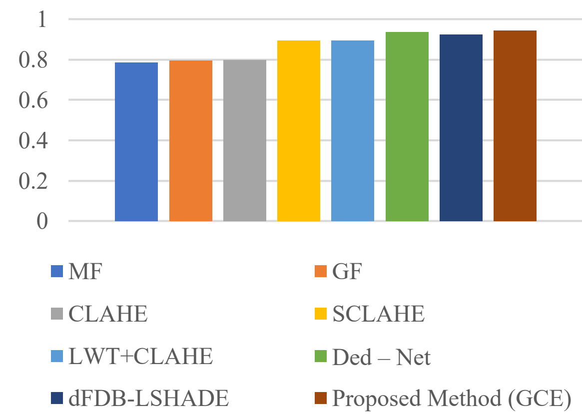

Fig. 6. SSIM of Sample Image S1 for all the Methods Tested

Table 5. Comparison of Enhancement Methods Tested for Accuracy.

Methods	Samples Tested	Resulted Good Quality Samples	Enhancement Accuracy (%)
MF	120	83	69.17
GF	120	81	67.50
CLAHE	120	96	80.00
SCLAHE	120	98	81.67
LWT + CLACHE	120	103	85.83
Ded – Net	120	107	89.17
dFDB-LSHADE	120	112	93.33
Proposed Method	**120**	**115**	**95.83**

From Table 5 it is very clear that the proposed method has enhanced the set of 120 samples and 115 sample images have been identified with good quality. Further the enhancement accuracy has been found as 95.83 % which is 2.61 % higher than the next best enhancement method.

Conclusion

Seven enhancement methods have been tested along with the proposed GCE method for dental image enhancement. The performance measurement has been done with the help of measuring MSE, PSNR, SSIM, LOE, CT and CR. The proposed method has achieved less MSE of 0.24 and high PSNR of 39.3514. Further the SSIM has been found good with a value of similarity 0.9436 with lowest LOE of 97, highest contrast ratio of 5.2:1 and with satisfactory computational time for sample 1 (S1). Which is 0.72 % higher SSIM, 25.24% higher PSNR, 25% reduced MSE, reduced LOR, 13.46% increased CR than Ded – Net method. And 2.12 % higher SSIM, 1.95% higher PSNR, 4% reduced MSE, reduced LOR, 9.62% increased CR than next best dFDB-LSHADE method. Similarly, the results produced for all samples are satisfactory and will be useful for next level of dental image segmentation and classification towards the best detection and treatment of dental diseases. It is very clear that the proposed GCE worked well on dental images and produced good results than the existing enhancement methods.

Author's Contributions

Krishnaveni R. has developed the algorithm for the proposed concept and formed the experimental setup and obtained the results. Sudarmani R was also involved in the development of algorithm. Both the authors have prepared the manuscript, verified and fine-tuned the manuscript.

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