Brightness Preserving Enhancement for Dental Digital X-ray Images Based on Entropy and Histogram Analysis

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Abstract

Enhancing dental x-ray images could be of great importance in helping the dentist for proper diagnosis. Image enhancement by histogram equalization, log transform, gamma correction for multiple gamma values, and contrast limited adaptive histogram equalization (CLAHE) were considered. Matlab 2015 was used to perform all the enhancement tasks. Dental x-rays images (periapical images) were obtained from a dataset published on the internet. It is preferred to preserve the x-ray images brightness so that the dentist can still use it for diagnosis with gray levels as close as possible to the originals. The CLAHE image enhancement, with eight rows and eight columns with clip limit of 0.01, proves to be the best. Two metrics were used for deciding the best enhancement, the entropy, looking for the highest obtained entropy, and the flatness of the resulted histogram. Eye inspection agrees with the metrics used.

Key Words: CLAHE, Dental X-ray Enhancement, Gamma Correction, Histogram Equalization, Image Entropy, Log Transform, Periapical Image

1. Introduction

Precise interpretation of medical radiographic images is essential for best patient healthcare. Periapical images refers to teeth digital radiograph images that dentists usually need to prescribe the optimum treatment [1]. Proper visualization characteristics of periapical images directly affect the quality of diagnoses [2]. In addition, the visual quality of any radiography image depends on two parameters contrast and brightness of that image [3]. Nowadays, digital radiography is widely used in dental clinics and acquisition of digital radiograph is faster and more helpful for dentists.

Therefore, image enhancement becomes one of the most important topics in image processing discipline. An enormous amount of researches have been done in the field of x-ray images enhancement. Nevertheless, the literature about dental digital x-ray images is limited. A study conducted by Yeong-Taeg Kim on contrast enhancement in 1997 [4], he focused on eliminating drawbacks of histogram equalization (HE) with the use of bi-histogram equalization. As a result, the histogram of the resulted image was around the mean. In 2010, an enhancement method based on Non-Linear technique was discussed by Foisal et al. [5]. The study was conducted on images with dark shadows using logarithmic transformation coefficient histogram matching.

M. Sundaram et al. has used histogram modified CLAHE (HMCLAHE) in 2011 to control the enhancement level of mammogram images in comparison to histogram equalization (HE) [6]. Then, in 2012, G. N. Sarage and Dr. Sagar Jambhorkar have used mean and median filtering techniques to enhance the quality of chest x-ray images by reducing their noise [7].
A proposed technique depended on mathematical morphology analysis was presented by Ritika and Sandeep Kaur in 2013 for contrast enhancement [8]. In this study, low contrast pixels in the image were reduced with the aid of histogram equalization (HE) and contrast limited adaptive histogram equalization (CLAHE) analysis. According to Ikhsan et al. in 2014, a new method was discussed to enhance the contrast of retinal images for diabetes patients [9], where three image processing techniques had been used: HE, CLAHE and GC (gamma correction) for contrast enhancement. Furthermore, in 2015, Datta et al. performed another study on retinal images preserving their brightness and quality in diabetic monitoring system [10]. They applied some performance parameters like average absolute mean brightness error (AAMBE) and structure similarity index measurement (SSIM) to preserve image quality during enhancement. Mehdizadeh and Dolatyar have conducted a study on digital periapical images (dental X-rays) by analyzing their adaptive HE [8]. Ahmad et al. discussed different techniques in their study to equalize the histogram of dental x-rays [11].

Different algorithms are currently used to enhance digital radiograph periapical images, each algorithm modifies the entropy and the histogram of the original image. Therefore, identifying the optimum enhancement algorithm depends on the resulted entropy and histogram [12]. In this research, algorithms were applied to twenty digital periapical images to analyze their entropy and histogram and eventually identifying the optimum enhancement algorithm.

The rest sections are arranged as following: background section revises the entropy and the potential enhancement algorithms. Materials and methods section discusses the equipment and tools that were used to perform this research. Results section explains the obtained results and compares between them. Discussion section lists all the aspects that could affect the results. Finally, conclusion and future works section summarizes the algorithms used and the chosen enhancement algorithm and how this research combines with other researches.

2. Background

In this section, a definition of the entropy and a description about the applied algorithms (techniques) are given so that the image enhancement procedure can be easily understood.

2.1 Entropy

Entropy was firstly introduced by Claude Shannon in 1948 [13], and it refers to the amount of the information that an image contains. The entropy of an image can be expressed as following:

$$\text{Entropy}(E) = -\sum_{k=0}^{n-1} P_k \log_2 P_k$$

(1)

$$P_k = \frac{\text{Occurrence of the intensity level } i}{\text{Number of intensity levels}}$$

(2)

where $k$ refers to the number of color levels within the image, $n$ equals here to 256 as grayscale images are considered.

2.2 Histogram Equalization

Histogram equalization (HE) is considered as one of the most popular image enhancing algorithms that is used in contrast enhancement. Hence, it is widely used in medical imaging applications, image matching, texture synthesis and image searching [14]. Contrast enhancement is achieved in this technique by redistributing (stretching) intensity values between bright and dark areas [15]. Thus, the dynamic range of the test image is stretched and flattened so that the contrast is improved [14]. As a result, the output image will show its clear details easily to the eye and it will assist the process of feature extraction in the image.

2.3 Logarithmic Transformation

Logarithmic transformation (Log Transform) is an image modifying algorithm that is concerned with enhancing the interpretability/perception of information in
digital images [16]. Log transform technique is set to show the frequency content along the gray level range of the image. Dark pixels values in the image are expanded in this technique whilst values of light pixels are compressed. Thus, narrow range of low/high values of gray level in the input image will be turned to wider range in the output image [17]. Log Transform is achieved in two steps; creating of phase preserving matrix and taking the logarithm on modulus of coefficients as stated in the following equation:

\[ X^*(i, j) = \log(X(i, j) + \lambda) \]  

(3)

where \( X^*(i, j) \) is the enhanced image after the transformation, \( X(i, j) \) refers to the original image, \( \lambda \) refers to the shifting coefficient, usually set to 1 to compensate for zero value of the pixels.

2.4 Gamma Correction

Gamma correction is an application of power-law transform or ‘raise to power’ technique in which the values of input pixels are raised to a set power, refer to equation (4) [18]:

\[ X^*(i, j) = C \times (X(i, j)^\gamma) \]  

(4)

where \( C \) refers to a constant factor that can be greater or lower than one, taken equals to 1, \( \gamma \) has been set in this experiment to four different values (0.2, 0.4, 0.6, 0.8).

Depending on the values of \( \gamma \), the contrast of high/low value image portions will be enhanced [18]. Thus, for \( \gamma > 1 \) image portions with high-values will be enhanced at the expense of low-values portions, and vice versa for \( \gamma < 1 \).

2.5 Contrast Limited Adaptive Histogram Equalization (CLAHE)

CLAHE is another image enhancing algorithm concerned with contrast enhancement. It is also a spatial domain based, used to optimize the input image by maximizing its entropy and limiting its contrast [19]. For medical images, good results has been produced using this algorithm [20]. CLAHE is based on dividing the input image into several non-overlapping regions with equal sizes and then set a desired clip limit for each region. In each block/region there are three different sub-regions: corner regions (CR), boarder regions (BR) and inner regions (IR) covering the whole block area. Thus, the histogram of each block will be firstly taken to obtain the desired clip limit, then each histogram will be redistributed so that its height does not exceed the set clip limit [20], see equation (5).

\[ g = \left[ g_{\text{max}} - g_{\text{min}} \right] \times P(f) + g_{\text{min}} \]  

(5)

where \( g \) is the computed pixel value, \( g_{\text{max}} \) is the maximum pixel value, \( g_{\text{min}} \) is the minimum pixel value, \( P(f) \) is the CPD (cumulative probability distribution).

3. Materials and Methods

MatLab 2015 was used to process and analyze 20 dental periapical images, Matlab reads the periapical images as a grayscale images. Then these grayscale images are represented as intensities in numbers ranging from (0) to (255). Black color is represented by (0), while white color is represented by (255) and all the other grayscale colors between white and black are represented in values between (0/255). Therefore, MatLab offers an excellent tool to show how the intensities would be modified according to enhancement applied algorithm [21].

All images were taken from a dataset that has been established for dental image analysis [22]. The periapical images that was used in this study were taken using conventional x-ray machine and digital sensors. The hardware and software, that is used in acquisitioning the periapical images, have been made by German company called Sirona [22]. Therefore, all images have been electronically transferred in same conditions to computer for further processing. Digital sensors were used instead of developing films to decrease the noise that might be added to images [22].

The visual quality of the tested images have been en-
hanced by different algorithms specifically histogram equalization, logarithm transform, gamma correction (GC) and contrast-limited adaptive histogram equalization (CLAHE). Gamma correction was applied for different gamma values specifically (0.2, 0.4, 0.6, & 0.8). In addition, eight rows and columns have been taken as CLAHE’s tiles with clip limit of (0.01). The visual quality of any image depends on two parameters, contrast, and brightness. These two terminologies are being modified according to change in entropy and histogram [3]. Consequently, the aim of this study is to choose the appropriate enhancement algorithm depending on analyzing the entropy and the histogram of enhanced images relative to the original image.

All tested images’ entropies before and after enhancement have been noticed to show how the entropy was modified according to algorithm used in terms of increasing and decreasing. Furthermore, histograms of the tested images are investigated for eventually choosing the flattened one. The following block diagram in Figure 1 summarizes the proposed method.

The optimum algorithm was identified based on two metrics. First, the entropy of the enhanced image should be higher than any other entropy resulted from other enhancement algorithms. Second, the histogram of the enhanced image should be flattened in comparison with other obtained histograms, but still refers to the original image histogram [12].

Next section discusses the results in details and how the images are differently enhanced according to algorithms used.

4. Results and Analysis

Results obtained from analyzing the first and second images are shown in Figures 2&3.

Results showed periapical images have been significantly enhanced using contrast-limited adaptive histogram equalization method (CLAHE) based on higher entropy obtained as shown in Table 1.

Table 1 clarifies that each algorithm modified the images’ entropy in terms of increasing or decreasing as compared to the original entropy. Table 1 shows that
higher entropy was obtained using CLAHE in the first place, followed by GC 0.8 and the rest of algorithms are ranked differently.

Furthermore, results show that CLAHE has increased the original entropy for all 20 tested images. Histogram equalization gives lowest entropy; while other algorithms modified the entropy lower than the original one in a slight change especially for algorithm of GC 0.8.

In addition, histograms of all 20 tested images were analyzed to assess the behavior of enhancement algorithms. CLAHE is considered the most suitable enhancement algorithm as it produces flattened histogram as shown in Figures 4&5. Figures 4&5 represent the histograms for first and second images before and after enhancements.

Histogram analysis shows that not all enhancement algorithm give flatter histogram. Histogram equalization has spread the pixels over the range of the grayscale with giving approximately same amount of pixels to all intensities.

Histogram resulted from Log Transform, GC 0.2, GC 0.4 and GC 0.6 are skewed to either left or right with lack of spread histogram. Although, GC 0.8 gives histogram similar to original one, the histogram resulted has not spread enough as the histogram resulted from CLAHE. Consequently, CLAHE can be considered the optimum enhancement algorithm as it gives flatter histogram and higher entropy as compared to other algorithms.

### 5. Discussion

Enhancing digital dental x-ray images using different algorithms were analyzed. The metrics used to judge the best enhancement was the entropy and the histogram of the enhanced images as compared with the original. The aim is to enhance the periapical images and preserve its brightness at the same time as far as possible. Entropy proves to be a good judging tool for this purpose, as the best enhancement gave maximum entropy value (CLAHE method), which was also nearest to the original image.

<table>
<thead>
<tr>
<th>Algorithm used</th>
<th>Original entropy</th>
<th>Hist. Eq. entropy</th>
<th>Log. tran. entropy</th>
<th>GC 0.2 entropy</th>
<th>GC 0.4 entropy</th>
<th>GC 0.6 entropy</th>
<th>GC 0.8 entropy</th>
<th>CLAHE entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image5</td>
<td>7.3274</td>
<td>5.9269</td>
<td>6.6689</td>
<td>5.8103</td>
<td>6.5389</td>
<td>6.9252</td>
<td>7.1547</td>
<td>7.7076</td>
</tr>
<tr>
<td>Image8</td>
<td>7.3248</td>
<td>5.9524</td>
<td>6.7376</td>
<td>5.9988</td>
<td>6.6709</td>
<td>7.01</td>
<td>7.2018</td>
<td>7.6675</td>
</tr>
</tbody>
</table>
entropy. The histogram of the enhanced images supports this point by giving a distribution that is some how flattened as compared to the original. The enhanced image histogram using (CLAHE) had near shape to original but much flattened. The used enhancement methods showed different results as following: firstly, histogram equalization method spread the image energy to form an image with rather different intensity as seen in its histogram. Secondly, log transform expresses low enhancement with histogram shifted towards low intensity side. Thirdly, gamma correction at low gamma value (0.2) shifts all the histogram to the high intensity giving much brighter image than needed. In addition, gamma correction values have not spread the histogram adequately; however the histogram gets flattened as the gamma value is increased. At gamma value of (0.8) the resulted enhanced image is similar to the input image as it is near to condition of (gamma = 1) giving original image.

CLAHE’s tiles was set as eight rows and eight columns with clip limit of 0.01. Increasing the tiles in both rows and columns would not affect the contrast and brightness of the enhanced image. However, the situation is different in manipulating the clip limit, increasing the clip limit would increase the brightness of the image and vice versa [23].

In addition, multiplying gamma correction and log transform by a factor modify the brightness of the enhanced image depending on the value of the factor. Factor less than one decreases the brightness, while factor higher than one increases the brightness.

6. Conclusion and Future Works

After testing twenty periapical images chosen arbitrary from published (120) images data set in [22], the best enhancement was achieved using (CLAHE) method. The metrics used for this purpose were the entropy value and the histogram distribution for each enhancement method. It can be said that the best enhancement was accompanied by maximum entropy value which is justified by inspecting the histogram for each case. Consequently, the entropy value decides the best enhancement in periapical images of this data set. Future work may extend to include normal dental x-ray images after digitizing them with appropriate enhancement for digitizing noises. Furthermore, this enhancement gives a good reason for working on diagnosing different teeth problems with accepted errors.

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