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Image quality enhancement in digital panoramic radiograph

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Abstract
One of the most common positioning errors in panoramic radiography is the palatoglossal air space above the apices of the root of maxillary teeth. It causes a radiolucency obscuring the apices of maxillary teeth. In the case of this positioning error, the imaging should be repeated. This causes the patient to be exposed to radiation again. To avoid the repetition of exposing harmful X-rays to the patient, it is necessary to improve the panoramic images. This paper presents a new automatic panoramic image enhancement method to reduce the effect of this positioning error. Experimental results indicate that the enhanced panoramic images provide with adequate diagnostic information specially in maxilla sinusoid region. Hence, this technique dispenses the need for repetition of X-ray imaging.

Keywords*: Image Enhancement, Gamma Correction, Panoramic Radiography, Gray Level Co-Occurrence Matrix, Homogeneity*.

1. Introduction
Panoramic radiographs are most useful clinical images for diagnostic problems requiring a broad coverage of the jaws. Common example includes evaluation of trauma location of third molars, extensive dental or osseous disease, known or suspected large lesions, temporomandilular joint (TMJ) pain and developmental anomalies [1]. It was reported that above 90% of panoramic radiographs have at least one positioning error. Figure 1 shows the most common positioning error in the radiographs. Once the patient's tongue is not contacted with the palate during the exposure, this error, known as palatoglossal air space, may occur [2].

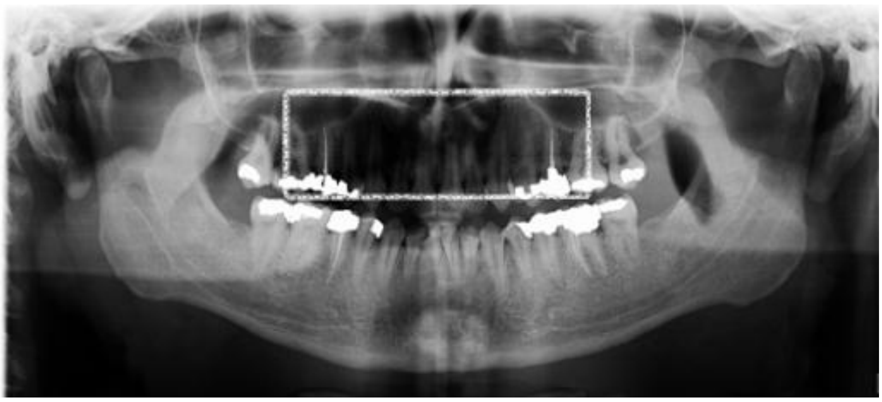

Figure 1. An example of a panoramic radiograph with a positioning error (The area depicted by the rectangle).

There is not any technical solution to solve this problem. Hence, the radiologist should again expose the X-ray to the patient to re-capture the image. This paper proposes a new technique to enhance panoramic images for better diagnostic information. This technique improves the visual appearance of panoramic image by increasing the contrast, adjusting brightness, and enhancing visually important features. This technique uses an adaptive approach to enhance the entire image especially in maxilla sinusoid region.

Due to technical limitations, many imaging devices do not display the actual appearance of objects. This technical limitation known as gamma distortion often disturbs the image. The gamma distortion in an image is not monotonic. It mainly depends on the relative illumination reflection of objects in the image. In other words, image distortion depends on the depth, texture, and relative reflection of objects in the image. Since a panoramic radiograph contains objects with a variety of texture and depth such as tongue and teeth, gamma distortions may not be the same as all objects. Hence, it needs an adaptive approach to enhance the image.

This paper proposes a new technique for estimating the gamma values in the panoramic image. For the local gamma correction the image is divided into overlapping windows. Then the gamma value of each window is estimated by minimizing the homogeneity of gray level co-occurrence matrix (GLCM).This feature indicates how details of objects are visible in the image; the lower the value of this feature represents more visibility of the image details. Using the homogeneity feature of the co-occurrence matrix to measure the visibility of image details, a proper gamma value will be assigned to each window.

Next section focuses on gamma correction for image enhancement. In Section 3, gray level co-occurrence matrix is presented. The proposed algorithm is introduced in Section 4. Sections 5 and 6 described the results, and the conclusions respectively.

2. Gamma correction

Gamma correction for image enhancement has been described in depth in [3,4]. Many devices used for capturing, printing or displaying the images generally apply a transformation, called power-law [5]; the image of each pixel of the image has a nonlinear effect on luminance:

$$g(u) = u^{\gamma} \quad (1)$$

In the above equation, $u \in [0, 1]$ denotes the image pixel intensity, γ is a positive constant introducing the gamma value. This equation using the value of γ typically can be determined experimentally through passing a calibration target with a full range of known luminance, which values through the imaging device. When the value of γ is known, inverting this process is trivial:

$$g^{-1}(u) = u^{1/\gamma} \quad (2)$$

Often such a calibration is not available or the direct access to the imaging device is not possible [6]. Hence an algorithm is needed to reduce the effects of these nonlinearities without any knowledge about the imaging device.

In addition to this problem, as mentioned before, these nonlinear effects aren't consistent across all regions of the image. In other words, the value of gamma may change from one region to another [6,7]. Hence a local enhancement process adjusts the image quality in different regions, so that the details in dark or bright regions are brought out to the human viewers [8].

It is noted that image enhancement techniques, such as a histogram equalization may not be used to enhance images suffering from gamma distortion. The main objective of histogram equalization is to achieve a uniform distributed histogram by using the cumulative density function of the input image. This may not be a suitable objective, where brightness of some areas (or objects) in the image is satisfactory [9]. In histogram equalization technique, the pixel values are either added or multiped by a value [5]. It mainly cares about histogram of the image not the actual appearance of the image which is the case in the gamma correction.

Hence, conventional image enhancement techniques, such as global brightness, contrast enhancement, and histogram equalization are incapable of providing satisfactory enhancement results for images suffering from gamma distortion.

Imaging devices apply the power-law transformation on each of the pixel image; hence, gamma correction is required to enhance each pixel of the image. Figure 2 shows an example of gamma correction superiority to histogram equalization in the image enhancement. The image enhancement using gamma correction has more subtle diagnostic information. We have used the co-occurrence matrix to find the image details for a better gamma estimation.

(a) Histogram equalization result (b) Gamma correction result

Figure 2. Comparison between gamma correction and histogram equalization in enhancing the panoramic radiograph shown in Figure 1.

3. Gray level co-occurrence matrix

The gray level co-occurrence matrix is often used for feature extraction in texture analysis of an image. The co-occurrence matrix of a gray level image is regarded as a two dimensional matrix. Its size is proportional to the number of gray levels in an image. For instance, the images used in this paper have 256 gray levels; thus, their GLCM is a matrix of size 256×256. In contrast to histogram, GLCM describes the relationship between the values of neighbouring pixels. It measures the probability that a pixel of a particular gray level occurs at a specified direction and a distance from its neighbouring pixels. This can be calculated by the function $P(i, j, d, \theta)$, where i is the gray level at location with coordinate (x, y), j is the gray level of its neighbouring pixel at a distance d and a direction θ from a location (x, y) [10]. θ usually ranges from: 0, 45, 90, to 135 [11]. This is mathematically defined by (3):

$$P(i,j,d,\theta) = \# \{(x_1, y_1)(x_2, y_2) | f(x_1, y_1) = i, f(x_2, y_2) = j, |(x_1, y_1) - (x_2, y_2)| = d, \angle((x_1, y_1), (x_2, y_2)) = \theta\} \quad (3)$$

In [12], fourteen different features of GLCM have been defined. These features consist of texture information, but there may be a correlation between them. This paper focuses on the homogeneity feature extracted from co-occurrence matrix P; this feature is illustrated below.

$$P(i,j,d,\theta) = \sum_{i}^{256} \sum_{j}^{256} \frac{P(i,j,d,\theta)}{1 + |i - j|} \quad (4)$$

Homogeneity returns a value that measures the closeness of distribution of GLCM's elements to the GLCM diagonal, and its range is from 0 to 1. In other words, it describes how uniform the texture is. Figure 3 shows three images with different gamma condition along with their co-occurrence matrix. As it can be conceived from the images, when the amount of γ is less than one, the transformed image becomes lighter than the original image (see Figure 3(a)); and when the amount of γ is greater than one, the transformed image becomes darker than the original image (see Figure 3(c)). When the gamma value is one, there is no change on the pixels value (see Figure 3(b)).
It needs to be noted that extracted homogeneity feature from associated co-occurrence matrix reveals that, this feature has the minimum value for image with good gamma condition. As discussed above, this feature represents how uniform the texture is. Figures 3(a, c) are two distorted images that their details are not clearly revealed. The details can be clearly seen in Figure 3(b), and the homogeneity value in Figure 3(e) indicates that the image is not uniform similar to the other two images.

(a) $\gamma = 0.2$ (b) $\gamma = 1$ (original image) (c) $\gamma = 3$

(d)HOM=0.56 (e)HOM= 0.40 (f)HOM=0.58

Figure 3. Three images with different gamma condition and their associated co-occurrence matrix with extracted homogeneity feature.

4. Proposed method

This paper proposed an adaptive gamma correction method to enhance the quality of panoramic images. As noted above in section…, these images often suffer from the root of maxillary teeth area. The basic idea is the fact that the homogeneity value in an image not suffering from gamma distortion has a lower value (near to zero). These homogeneity values can be calculated by co-occurrence matrix. The gamma value is then estimated by minimizing these homogeneities.

The image in the adaptive gamma correction is divided into overlapping windows. A sliding window of size 100×200 is moved across the image from the top-left side to the bottom-right by fifty pixels in each movement. A value of 100×200 pixels was chosen for images with the size 1500×3000 as this window size gives the best trade-off between the rendering of local details and the need for reducing space dimensionality. To find a proper gamma value for each window, we apply a range of inverse gamma values from 0.1 to 3 intervals 0.1 in each window. Different windows may need different gamma value for a proper enhancement. To find the best gamma value for each window, we compute the co-occurrence matrix of the window to extract the homogeneity feature. Then, the gamma value associated with the minimum homogeneity is considered as the best gamma value for enhancement.

Figure 4(a) displays a window of panoramic image. To find a proper gamma value for enhancing this window, different inverse gamma values are applied on the window and the homogeneity value is computed. Then the homogeneity values are plotted as a function of inverse gamma values (see Figure 4(d)). The gamma value associated with the least homogeneity offers the most suitable one for enhancing the window. Figures. 4(b,c) were modified with $\gamma^{-1} = 0.53$ and at $\gamma^{-1} = 1.67$.

In this approach, each window in the image has its own gamma value. Because of overlapping windows, pixels may settle under different windows; hence, different gamma values may apply. We apply only one gamma value on each pixel, which is the average of the gamma values in the covering windows. In other words, a matrix M of gamma values with the same size as the image is achieved. To enhance the image, according to equation (2) the gamma values are applied to each pixel. Figure 5(a) shows the result. As it is shown in this figure, this approach has unpleasure blocking effects on the image.

In this step, to eliminate the blocking effects, first we apply average filter on M containing the gamma values. Then the filtered gamma values are applied to the image for gamma correction. Figure 5(b) shows this result. Clearly, the blocking effects have been removed.

5. Experimental results

As mentioned earlier, one of the most common positioning errors is due to not contacting the tongue with the hard palate during capturing. It causes large airway shadow to be created over the roots of the maxillary teeth due to the gamma distortion. Hence, the goal of the present research is to estimate the gamma value of a panoramic image in a local approach. To evaluate the performance of the proposed approach in the enhancing a panoramic image, we have used thirty different radiograph samples collected at Babol Oral & Maxillofacial Radiology Center, Babol, Iran. This technique improves the quality of all the thirty radiographs, and considerly removes the large airway shadow over the roots of the maxillary teeth. The results of four samples with our proposed method are illustrated in Figure 6. As can be observed, in addition to improving the overall images, roots of maxillary teeth are also clearly visible. In general, it can be concieved that the enhanced images with our proposed method looks much better with more details compared to the original image.

6. Conclusions

The palatoglossal air space shadow appears, as a radiolucent area over the apices of the maxillary teeth is one of the most common errors in panoramic radiography. This effect reduces the diagnostic quality of radiographs. A new gamma correction method for panoramic radiography image enhancement is proposed in this paper. This proposed method improves the overall image especially the roots of maxillary teeth. The finding provides dentists with a sufficient amount of information to improve their diagnosis.

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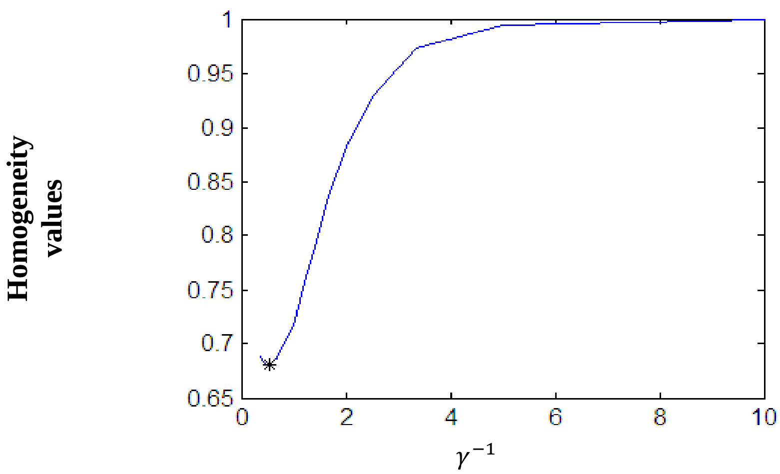
(a) Original image

(b) Modified image with $\gamma^{-1} = 0.53$

(c) Modified image with $\gamma^{-1} = 1.67$



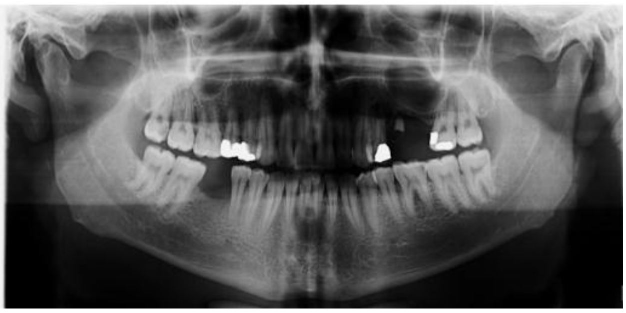
(d)

Figure 4. Diagram of homogeneity values for thirty different inverse gamma images from 0.1 to 3. The deep point represented by the asterisk reaches a unique minimum at $\gamma^{-1} = 0.53$.

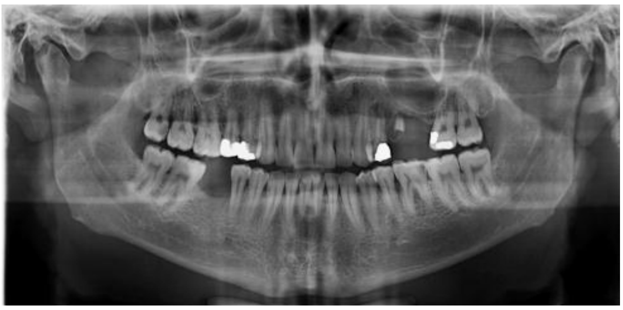
(a)

(b)

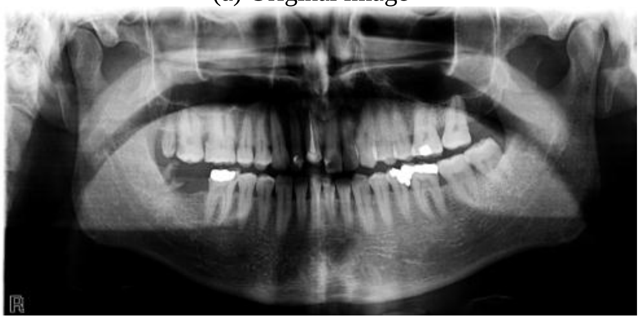
Figure 5. (a) Image enhancement with blocking effects in gamma correction, (b) Image enhancement without the problem of blocking effect.



(a) Original image



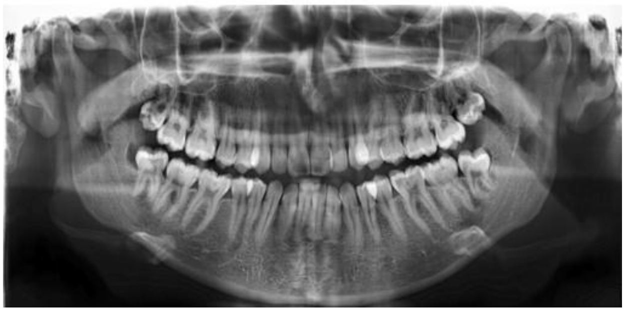
(b) Proposed method



(c) Original image

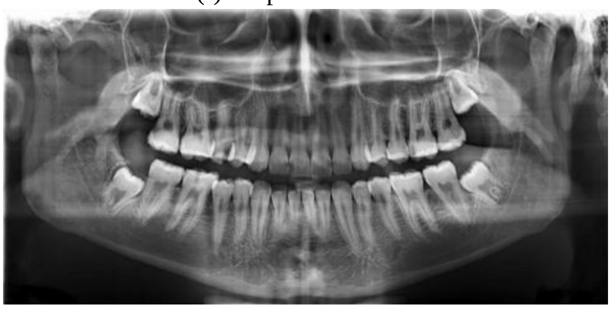
(d) Proposed method

(e) Original image



(f) Proposed method

(g) Original image



(h) Proposed method

Figure 6. Image enhancement by our proposed method.