Original Article

Removing Distortion of Periapical Radiographs in Dental Digital Radiography Using Embedded Markers in an External frame

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Submission: 19-09-2012 Accepted: 06-10-2012

ABSTRACT

To carry out *in vivo* and *in vitro* comparative pilot study to evaluate the preciseness of a newly proposed digital dental radiography setup. This setup was based on markers placed on an external frame to eliminate the measurement errors due to incorrect geometry in relative positioning of cone, teeth and the sensor. Five patients with previous panoramic images were selected to undergo the proposed periapical digital imaging for *in vivo* phase. For *in vitro* phase, 40 extracted teeth were replanted in dry mandibular sockets and periapical digital images were prepared. The standard reference for real scales of the teeth were obtained through extracted teeth measurements for *in vitro* application and were calculated through panoramic imaging for *in vivo* phases. The proposed image processing thechnique was applied on periapical digital images to distinguish the incorrect geometry. The recognized error was inversely applied on the image and the modified images were compared to the correct values. The measurement findings after the distortion removal were compared to our gold standards (results of panoramic imaging or measurements from extracted teeth) and showed the accuracy of 96.45% through *in vivo* examinations and 96.0% through *in vitro* tests. The proposed distortion removal method is perfectly able to identify the possible inaccurate geometry during image acquisition and is capable of applying the inverse transform to the distorted radiograph to obtain the correctly modified image. This can be really helpful in applications like root canal therapy, implant surgical procedures and digital subtraction radiography, which are essentially dependent on precise measurements.

Key words: *Dental, image analysis, periapical, radiography*

INTRODUCTION

Nowadays, digital dental image analysis is widely employed in diagnosis, treatment planning, and prognosis by dentists.[1-5] Digital imaging can be utilized in endodontic applications, evaluations after and before implant surgery, and dental processes needing multiple imaging.

However, the distortions caused by incorrect angulations of radiographic cone toward the teeth and the sensor must be solved by additional image processing methods; otherwise, such a distortion may cause inevitable errors, likely to affect the measurements which are very important in procedures like root canal therapy, implant surgery and subtraction radiography.

To eliminate this misrepresentation, we proposed a noninvasive method in radiographic imaging. This method introduces a new arrangement in geometry of radiographic imaging in order to provide a condition to measure the changes appeared due to incorrect placement of cone toward the teeth and the sensor. Consequently, this method can remove these unwanted changes from the affected image by applying an inverse transform.

MATERIALS AND METHODS

In the first phase of the study, the *in vitro* phase, quantitative measurements were calculated on 40 extracted teeth which were then replanted in dry mandibular sockets to undergo periapical imaging [Figure 1]. In the second phase, the *in vivo* phase, digital panoramic radiographs of 5 volunteers, in Dental School of Isfahan University of medical sciences were used as standard references and the patients kindly accepted and signed consent forms which let us taking an extra periapical image in our proposed setup.

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The measurements on real teeth were performed by a caliper. The widest part of the tooth was measured for horizontal measurement and the distance from end to end was evaluated to represent the vertical length. Knowing the resolution of imaging device, the measured values were calculated in pixels and were used as gold standards in error estimation. For the second phase of study, measurements on digital panoramic images were simply done by getting the cursor's location through mouse clicks of the expert.

In order to remove the image distortions, a new method based on embedded landmarks aligned by an external frame was applied. For this purpose, we designed a radiolucent frame covered with a rectangular network. The proposed width for comprising lines is 0.2 mm and the side length for parallelograms is suggested to be 2 mm. [Figure 2a] The most important shortness of our previous method[6] was the superimposition of the embedded square mesh with the region of interest (periapical zone), which could cause misdiagnosis [Figure 2b]. To solve this problem, a special frame with an empty area in lower part of the frame was designed to be used instead of a full cover of squares [Figure 2a]. Furthermore, we used smaller mesh compared with our first experiment to improve the accuracy of the method.

The frame was mounted on the top of the radiographic cone without any intrusion on the patient [Figure 3]. The proposed imaging technique for periapical radiography is a combination of parallel and bisecting periapical image acquisition methods.[7] To clear up, the angle between tooth and sensor is similar to bisecting method, however, the angle between the cone and the tooth is like parallel imaging. In standard geometry (parallel frame with the sensor, and both parallel with the teeth), the squares on the frame would appear with a same size in the acquired image. However, if the parallelization is not provided, the squares would be distorted and skewed and would appear in a shape of rectangles or trapezoids.

At this stage, by calculating the imposed distortion on squares, the overall image distortion can be estimated and corrected. In this method, after applying noise removal in preprocessing step, the proposed image processing algorithms are applied to find specific points (Landmarks) on each image[8] [Figure 4].

The locations of the detected points (depicted by green markers in Figure 5) were compared to corresponding positions in the case of standard geometry (depicted by red markers in Figure 5). The respective coordinates are then utilized to correct the distortion (magnification, translation and rotation) by a projective transform, which needs at least four points for estimation of the transform (four corners of one square are proposed to be used in this step). The basic formulas of a projective transform are like[9]:

Figure 1: Extracted tooth replanted in a dry mandibular socket

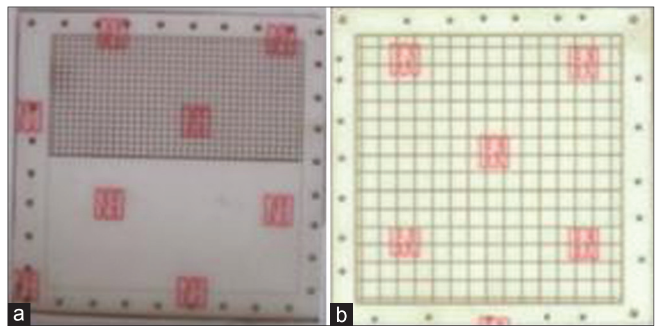

Figure 2: (a) Intersecting vertical and horizontal radio-opaque lines (square mesh) on the frame with smaller squares on the upper part of the frame. (b) Old frame with bigger squares on the whole area

Figure 3: The frame installed on the top of the radiographic cone

$$[u_p \quad v_p \quad w_p] = [x \quad y \quad w] \times T_{inv}$$

Where:

$$u = \frac{u_p}{w_p} \; v = \frac{v_p}{w_p}$$

Assuming:

$$T_{inv} = \begin{bmatrix} A & D & G \\ B & E & H \\ C & F & I \end{bmatrix}$$

$$u = \frac{Ax + By + C}{Gx + Hy + I}$$

$$v = \frac{Dx + Ey + F}{Gx + Hy + I}$$

An example of the corrected image is demonstrated in Figure 6, where the incorrect magnification, translation and rotation are all removed and the squares are in the accurate size of squares in standard geometry. Therefore, we can expect the dental structures to have the right size, similar to what was expected in an ideal case of imaging (parallel frame with the sensor, both parallel with the teeth).

RESULTS

The results of this research are categorized in two groups. In order to evaluate the results of the first group, the extracted teeth were replanted in dry mandibular sockets and the images were taken *in vitro*. The most important advantage of *in vitro* phase is that the real length and width of each tooth could be measured manually and exactly, therefore the calculation of errors could be more reliable. However, it is crucial to establish a real condition to examine the actual performance of the method. Therefore, the accuracy of the proposed method was checked in the second phase of the research that took place through *in vivo* radiographic examinations. For this purpose, the real length and width of each tooth cannot be measured manually (since the teeth is not extracted) and digital panoramic images of the same person can be used for the calculations. Table 1 shows the examined teeth in this step (20 incisors, 10 premolars and 10 canins).

In the first phase, quantitative results were calculated on 40 extracted tooth collected and replanted in dry mandibular sockets and the areas were imaged in 7 situations, one standard geometry, 3 incorrect geometries with 10, 20 and 30 degrees between sensor and the teeth [Figure 7a] and 3 incorrect geometries with 10, 20 and 30 radial degrees [Figure 7b] between sensor and parallel plane to the tooth.

To calculate the efficiency of the method, we have:

$$XX[mean\,horizontal\,error] = \frac{\sum_{i=1}^{num\ of\ images} |X_i - X_{ri}|}{num\ of\ images}$$

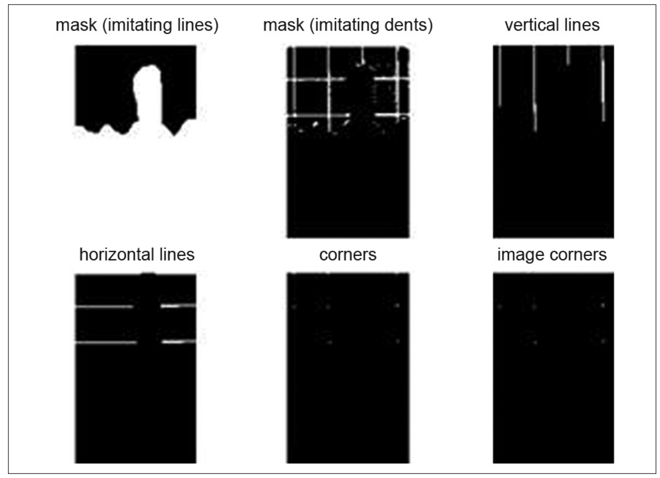

Figure 4: Some image processing algorithms applied in order to find specific points

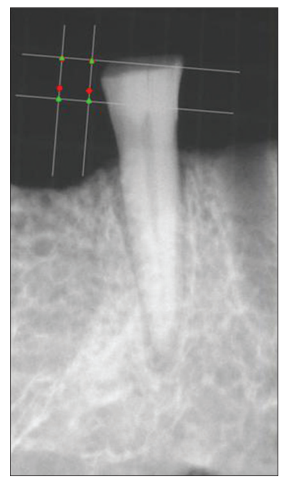

Figure 5: A sample *in vitro* image. Green points indicate the detected points and the red Points are the ones which should be found in the case of standard geometry

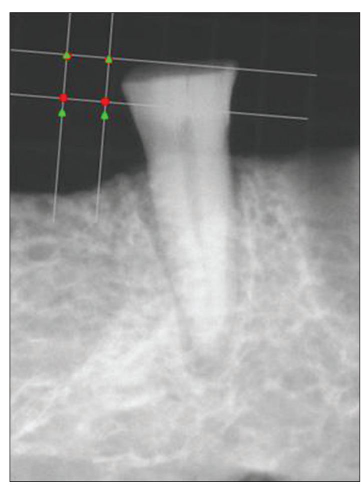

Figure 6: The modified image

$$YY[mean\,vertical\,error] = \frac{\sum_{i=1}^{num\ of\ images} |Y_i - Y_{ri}|}{num\ of\ images}$$

$$Err\,[mean\,rational\,Error] = \frac{\sum_{i=1}^{num\,of\,images}\left(\frac{|X_i - X_{ri}|}{X_{ri}} + \frac{|Y_i - Y_{ri}|}{Y_{ri}}\right)}{2 \times num\,of\,images}$$

$$TA[Total\,Accuracy] = \{1 - Err\} \times 100$$

Where Y_i is the length of each tooth and X_i is the related width [Figure 8], both calculated after imposing the proposed transform. X_{ri} and Y_{ri} are real magnitudes which can be measured from the extracted teeth. *TA* (Total accuracy) in an ideal method should be equal to 100% (no difference between measured and calculated lengths). *XX* indicates the mean value of horizontal error in millimeters and similarly *YY* indicates the mean value of vertical error in millimeters. In order to have a better visualization of the performance, *Err* (mean rational error) is calculated to show the mean value of expected error in measurement of each millimeter. For example, *Err* = 0.02 means that the expected outcome in measuring one millimeter is between 0.98 to 1.02 mm. Table 2 and Figure 9 show the mentioned values for our proposed method. It also should be noted that the errors in standard geometry may be expected not to be zero due to magnification which is shown in Figure 7A. However, since we know the exact size of the squares on the frame, we finally rescale the whole image to give the correct size to the squares and consequently to remove the magnification error.

In the second phase, Y_{ri} are magnitudes calculated from digital panoramic radiographs of 5 volunteers, who underwent the panoramic imaging in Dental School of Isfahan University of medical sciences and kindly accepted to be taken an extra periapical image in our proposed setup [Figure 10]. Since the horizontal measurements of panoramic imaging are not as accurate as vertical assessments, we just consider the vertical errors in our calculations. Table 1 shows the corresponding results for the proposed method.

Table 1: Errors and accuracy of the proposed method through *in vivo* phase

	Incisor (up)	Incisor (down)	Canin (up)	Canin (down)	Premolar (up)	Premolar (down)	Total mean
*YY*2 (mm)	0.311	0.341	0.482	0.458	0.347	0.348	0.381
*Err*2	0.03	0.032	0.042	0.041	0.033	0.035	0.035
*TA*2	97	96.8	95.8	95.9	96.7	96.5	96.4

Table 2: Errors and accuracy of the proposed method through *in vitro* phase

	θ=10	θ=20	θ=30	Total mean
XX (mm)	0.343	0.39	0.46	0.39
YY (mm)	0.64	0.773	0.871	0.76
Err	0.035	0.041	0.043	0.039
TA%	96.5	95.9	95.7	96.0

$$YY2\,[mean\,vertical\,error] = \frac{\sum_{i=1}^{num\ of\ images}|Y_i - Y_{ri}|}{num\ of\ images}$$

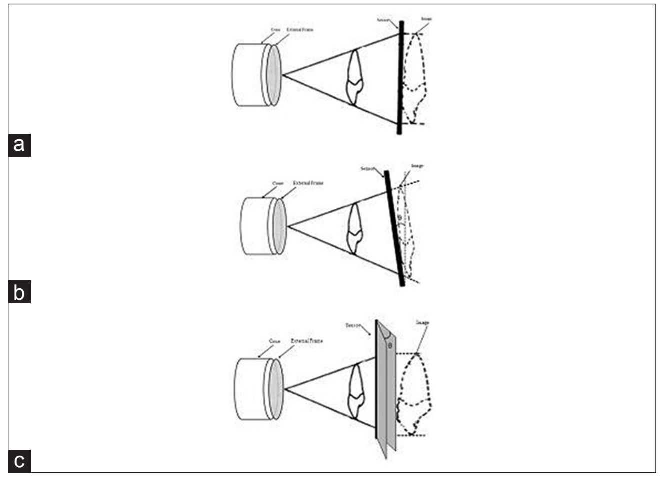

Figure 7: (a) Standard geometry; (b) Incorrect geometries with θ degrees between sensor and the teeth; (c) Incorrect geometries with θ radial degrees between sensor and the teeth

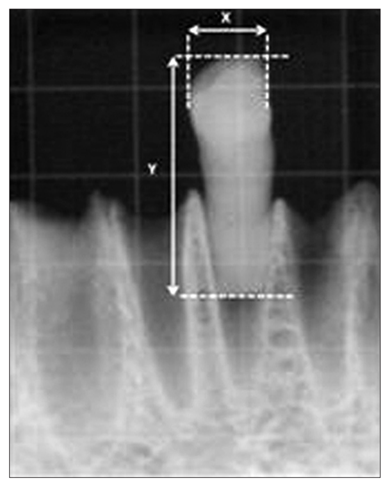

Figure 8: X and Y measurements

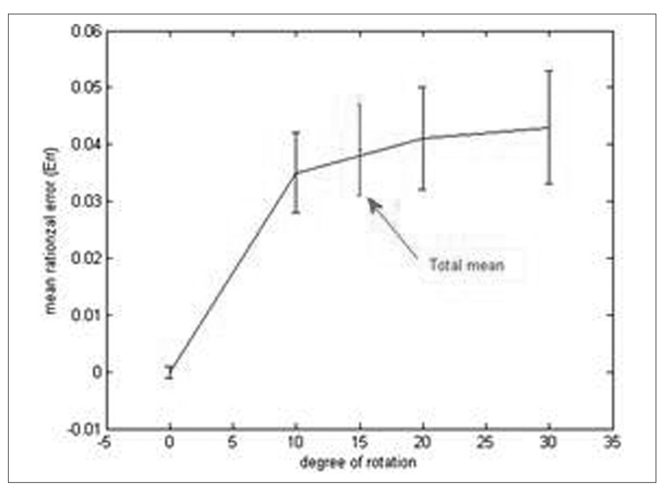

Figure 9: *Err* (mean rational error) for our proposed method with different degrees of distortion

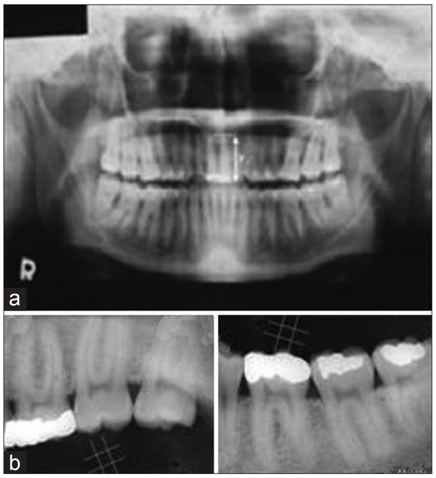

Figure 10: Sample panoramic image and two periapical images

$$Err\,2[mean\,ration\,Error] = \frac{\sum_{i=1}^{num\ of\ images}\left(\frac{|Y_i - Y_{ri}|}{Y_{ri}}\right)}{num\ of\ images}$$

$$TA2[Total\ Accuracy] = \{1 - Err\} \times 100$$

DISCUSSION

The proposed distortion removal method is perfectly able to identify the possible inaccurate geometry during image acquisition and is capable of applying the inverse transform to the radiograph to obtain the modified image.

This can be really helpful in applications like root canal therapy, implant surgical procedures and digital subtraction radiography, which are essentially dependent on precise measurements. However, it should be noted that the automatic discrimination of corner points of the rectangle in images with low quality (like Figure 10b) is cumbersome and in some cases it fails. To overcome this shortcoming, a user interface is designed to get the corner points interactively or accept any change to the results of the automatic corner detection by the expert. This semiautomatic method can even improve the results and simultaneously make the method applicable to images with very low quality.

Furthermore, we should mention that the best standard for comparison of *in vivo* results is cone beam CT. However, the patients referred to experience cone beam CT imaging technique are usually suffering from severe illnesses and we could not find any volunteer to undergo our proposed setup of periapical imaging. Therefore, we had no choice except comparing our result with panoramic images. In order to achieve reliable results, the panoramic imaging parameters were set to 100% scale which is introduced to transform the images to have their real lengths.

Another interesting point in this study is that the results of *in vitro* phase show lower accuracy than *in vivo* cases. This may be a result of applying very high distortions (30 degrees) during *in vitro* imaging, a value which is really rare to happen during *in vivo* imaging.

In conclusion, the proposed method can provide better digital dental radiographic images through removing foreshortening and elongation errors and can be used for the more accurate interpretation of dental radiographic images. Furthermore, by applying the differential methods, it makes treatment procedure more accurate and provides successful patient follow-up.

REFERENCES

1. Mol A, van der Stelt PF. Application of digital image analysis in dental radiography for the description of periapical bone lesions: a preliminary study. IEEE Trans Biomed Eng 1991;38:357-59.
2. Goebel P, Belbachir A, Truppe M. Background removal in dental panoramic x-ray images by the a-trous multiresolution transform. Proceedings of the European Conference on Circuit Theory and Design; vol. 1. 2005. p. 331-4..
3. Yasuda Y, Yashiro K, Takada K. Digital mapping of the interocclusal distance during biting by image processing of occlusal registration. IEEE EMBS Asian-Pacific Conference on Biomedical Engineering; 2003. p. 272-3.
4. Leung C, Yiu K, Zee K, Tsui W. Image registration in intra-oral radiography. Engineering in Medicine and Biology Society, 2005, 27th Annual International Conference of the Engineering in Medicine and Biology Society, 2006. p. 3206-9.
5. Lu X. Design and implementation of cooperative distributed dental medical information system. Proceedings of the Ninth International Conference on Computer Supported Cooperative Work in Design; 2005. p. 799-803.
6. Kafieh R, Shahamoradi M, Lotfi Mahyari T, Hekmatian E, Foroohandeh M, Emamidoost M. A method for removing distortion of periapical images in dental digital radiography. 3rd Congress of Oral and Maxilofacial Radiology; 2011; Tehran, Iran; 2011. p. 132-36.
7. Bean L. Comparison of bisecting angle and paralleling methods of intraoral radiology. J Dent Edu 1969;441:33-45.
8. Jain AK. Fundamentals of digital image processing: Prentice hall: Englewood Cliffs, NJ; 1989.
9. Zisserman A. Notes on geometric invariance in vision. Tutorial, British Machine Vision Conference; 1992.

How to cite this article: Kafieh R, Shahamoradi M, Hekmatian E, Foroohandeh M, Emamidoost M. Removing distortion of periapical radiographs in dental digital radiography using embedded markers in an external frame. J Med Sign Sens 2012;2:219-24.

Source of Support: Nil, **Conflict of Interest:** None declared

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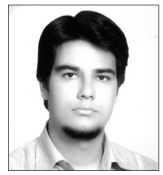

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