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Fast algorithm for detection of reference spheres in digital panoramic radiography

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ABSTRACT

In this paper, an algorithm for detection of reference spheres from digital panoramic radiographic images is presented. The proposed algorithm was tested on a database of 107 digital panoramic radiographic images which were used for dental diagnostics. Results show that the proposed method exhibits for detection of reference spheres, a sensitivity of 97.33% and specificity of 93.85%. Performance time differed between 0.55 and 2.36 s depending on image size. The aim of this work was to provide a fast ellipse detection algorithm to reduce measuring time on preoperative implant planning by lowering the computational cost.

1. Introduction

Dental panoramic radiographs and length measurements on dental radiographs are widely used for surgical planning in the field of dental implantology or other procedures in oral surgery [1–5]. A major problem about length measurements in dental panoramic radiographs is the intrinsic distortion resulting from the tomographic image acquisition technique [1]. It is a well-known fact, that a panoramic image of a curved image layer approximating the jaws is produced by rotating the source linked to the image receptor around the patient's head. The speed of the narrow X-ray beam relative to the structures is matched to the speed of the detector. A sharp projection of objects is only provided if they are located in a layer for which the movement of the X-ray beam and the detector has the same velocity. However, structures are reproduced with characteristic horizontal distortions through the relative movement of the X-ray beam and the detector. Rotational panoramic radiography projects the structures placed within the focal trough as tomographic images with minimal distortion. Even if structures are within the focal trough, the sharpness of the image is affected by the position of the structures, the difference in the relative speed of the X-ray source against the film and the difference in the direction of rotation. Due to the eccentric vertical position of the source, additional distortions are introduced. A third factor which makes precise measurements difficult is the fact that all panoramic radiographs are magnified approximately 30% even when the patient is ideally positioned [1]. A common known solution to minimize measurement errors in dental panoramic radiographs is the use of metallic reference spheres, which are positioned before radiological examination [5–8]. Then the visible diameter of the spheres is measured manually and related to the measured bone height of interest. Automated detection of the sphere shadows for automated correction of magnification would fasten the evaluation and should enhance reproducibility. Thus the aim of this work was to provide a fast ellipse detection algorithm to reduce measuring time on preoperative implant planning by lowering the computational cost for detection of the reference spheres. A major problem in detecting the projected shadow of the reference spheres in panoramic radiographs is their highly variable, non-uniform appearance due to the complex projection geometry. On intraoral or extraoral films, taken in fixed position, the reference spheres might appear as round disks or elliptical cone sections [9,10], but the motion of detector and X-rays in panoramic devices leads to additionally oval distortions of the shadows. The aim of this study was to introduce a fast algorithm for automatic detection of spherical or oval reference bodies in digital dental panoramic radiographs. The performance of the algorithm is evaluated and experimental results are presented.

2. Materials

A set of 107 digital panoramic radiographs were taken from our outpatients undergoing dental implant surgery in 2006. All radiographs were exposed with the digital Orthophos XG (Sirona Dental Systems, Bensheim, Germany). This panoramic device operates with a CCD-sensor providing an individual pixel size of $27 \times 27\,\mu m$. The signals are acquired at a bit depth of 16 bit (= 65 536 gray levels), but subsequently scaled in the default pre-processing procedure to 8 bit (= 265 gray levels). The images were exported as 8-Bit Windows Bitmaps by the proprietary software (Sidexis XG, Sirona Dental Systems, Bensheim, Germany). The size of the examined images

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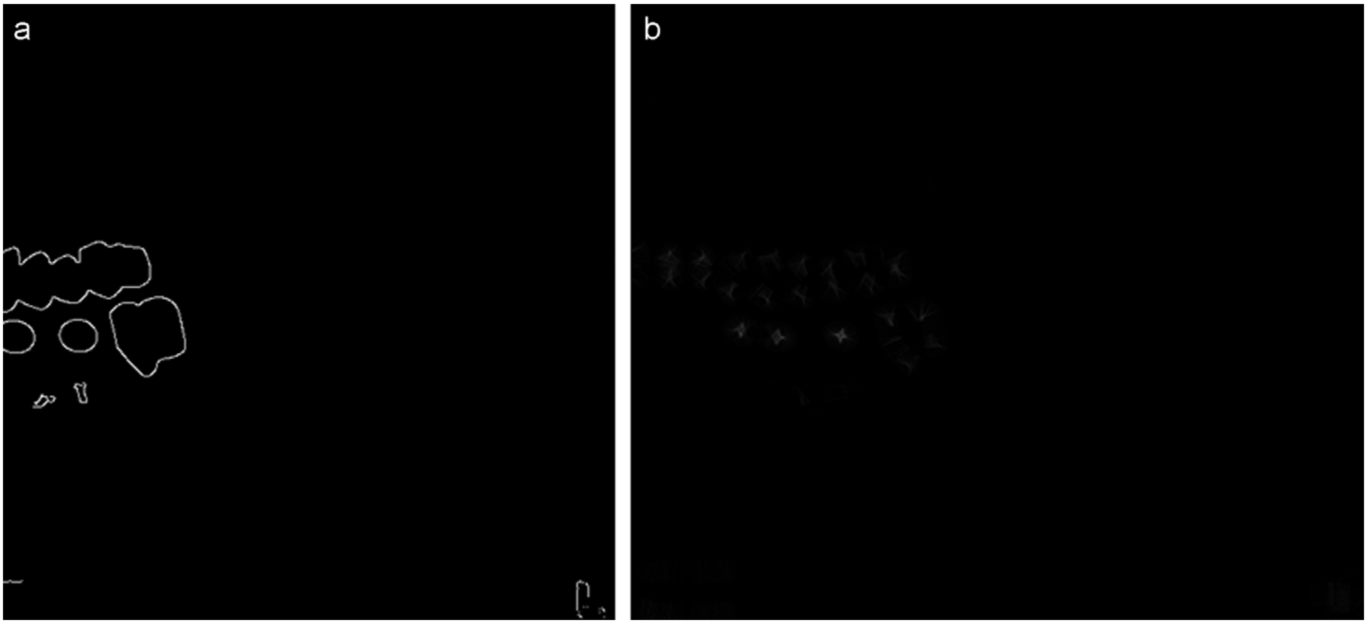

Fig. 1. Edge detection results (a) and accumulated object centers in parameter space (b). Note the maxima at the centers of the sphere shadows.

varied between 2940×1552 pixels and 960×1292 pixels, depending on the mode of image acquisition (half side panoramic radiographs of the size of 960×1292 pixels were not excluded). The detection algorithms described in this section were realized with Borland's Delphi 7 IDE (Borland GmBH, Langen) on a Sony VAIO VGN-SZ2XP/C (Sony Corporation, Japan) with an Intel Centrino Duo 2 GHz Processor and 1GB Memory and Windows XP (Microsoft Inc., Redmond, USA).

3. Methods

A software program was developed using the Delphi 7 IDE (Borland), which is able to open the digital radiographs as uncompressed bitmaps as exported by the Sidexis XG software and detects the spheres using algorithms described here. The pixel data is transferred to a two dimensional array for fast pixel calculations. In addition, several copies of this array are created to memorize intermediate data like edge detection results and calculated barycenter of the sphere shadows. In the first step, two two-dimensional image arrays are calculated with the sobel gradients gx and gy in x- and y-direction [11,12]:

$$gx = g^* \begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix}; \quad gy = g^* \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} \tag{1}$$

The results are stored for edge detection according to the method described by Canny [13] following the source code in [14]. Additionally the gradient direction information is used to calculate the barycenters of convex objects in the image using following equations [11]:

$$x_c = x - R(g_x^2/g) \tag{2}$$

$$y_c = y - R(g_y^2/g) \tag{3}$$

Here, x_c and y_c denote the estimated barycenters of the spherical objects, and R a stepwise increased radius (here the stepsize of R is increased in pixels). From Eqs. (2) and (3) a large number of points is accumulated in a two-dimensional parameter space according to their examined edge points. The estimated barycenters can be found in this parameter space as local maxima, which are selected by a predefined threshold (see Fig. 1). Since the shadows of the reference spheres are either round, elliptical or oval it is possible to reduce classification of the objects to a simple accumulation in a one-dimensional histogram representing the distances of the objects midpoints to its boundary (edge). The set of boundary points that contribute to a maximum in the parameter space is used to construct a histogram of radius values R_q obtained from

$$R_q = l = \sqrt{(Mx - E^i x)^2 + (My - E^i y)^2} \tag{4}$$

where l denotes the calculated length between the barycenter $M(x,y)$ and the corresponding boundary points $E^i(x,y)$. R_q is rounded and then accumulated into a histogram $f(l)$.

$$f(l) = |\{E^i | \sqrt{(Mx - E^i x)^2 + (My - E^i y)^2} = l\}| \tag{5}$$

Where $f(l)$ denotes the height of the histogram for the length l. By doing so, a voting histogram for every accumulated barycenter is created (see Fig. 2) for fast classification of the sphere shadows. Classification in the one-dimensional histogram is realized by searching the maximum peak in a predefined interval of the radii e.g. between 3 and 16 pixels (see Fig. 3). If the identified peak is higher than 15 entries between the selected radius-interval the examined object is accepted as sphere:

$$\exists l \in [3,16] | \quad f(l) > 15 \tag{6}$$

The searching interval is empirically predefined depending on the size of the used reference spheres.

4. Results

A total of 107 digital panoramic radiographs displaying between one and nine shadows of metallic spheres (diameter: 5.0 mm) was tested with the algorithm introduced above. The size of the images varied between 2940×1552 pixels and 960×1292 pixels. The software program finds the sphere shadows with a sensitivity of 97.33%. The sensitivity was measured the common way. Counting the total of applied spheres in the X-ray images was used to calculate the false negatives by subtracting the total of accurate detected ellipses