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Automatic Correspondence using the Enhanced Hexagonal Center-based Inner Search Algorithm for Point-based Dental Image Registration

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Abstract- **In this paper a modified version of the Center-Based Inner Search algorithm, the Enhanced Hexagonal Center-Based Inner Search algorithm, for automatic point correspondence is proposed towards dental registration. The modified algorithm is incorporated within a general registration scheme which is based on extracting a set of candidate points on the reference image, finding their corresponding points in the other image (float image) using the proposed algorithm and applying an affine geometrical transformation towards automatic registration. The performance of the proposed algorithm is evaluated against a well-known method for automatic correspondence, in terms of the registration accuracy. Qualitative and quantitative results on registering 24 dental pairs showed that the proposed algorithm outperforms the other method for automatic correspondence.**

Index Terms- **Automatic point extraction, automatic correspondence, dental image registration, enhanced hexagonal center-based inner search.**

I. Introduction

The diagnostic problem of comparing radiographic dental images over time lies primarily on the identification of the image features that are solely related with the progression of a particular disease. Experts commonly identify changes in the bone structure supporting the teeth by comparing radiographs acquired over a short or long period of time. Studies have shown that the success of subtraction radiography between the reference and the follow-up images depends on the level of standardization of the projection geometry [1]. However, the standardization of the projection geometry during acquisition is only the first step towards successful subtraction radiography. Since the reproducibility of imaging geometry can not be guaranteed, spatial registration is often required before subtraction.

Various automatic image processing techniques have been proposed towards registration of dental images [2]. The majority of them are based on the automatic segmentation of specific structures prior to registration, while others on the gray levels of the image [3]-[4]. On the other hand, point-based registration involves the determination of the coordinates of corresponding points in different images, either manually or automatically, and the estimation of a geometrical transformation using these corresponding points.

In this paper we present a general automatic registration scheme for point-based registration of dental images. The scheme is based on extracting a set of distinctive points on the reference image, finding their corresponding points in the other image (float image) and applying a geometrical transformation towards automatic registration.

II. Methodology

The proposed scheme for point-based registration of dental images is shown in Fig. 1.

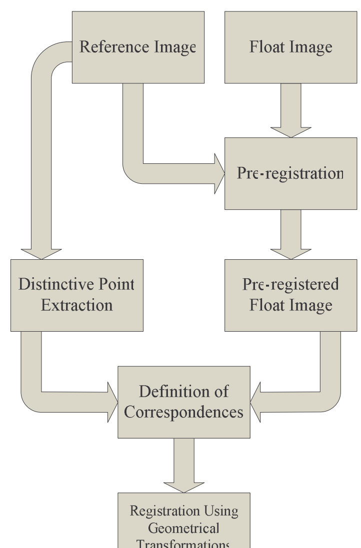


Fig. 1: Block diagram of the proposed point-based registration scheme.

According to this figure, the scheme comprises of the following processes:

- Pre-registration of pairs of dental images
- Distinctive point extraction from the reference image
- Definition of automatic correspondence
- Registration using geometrical transformation

1. Pre-registration of dental images

In order to improve the performance of the proposed automatic correspondence method, a pre-registration process is required, which will eventually allow the algorithm to converge faster and produce more accurate estimates. The two radiographic dental images, one corresponding to the reference image, I_R, and the other to the floating image, I_F, are pre-registered using simple translations in the x and y axes. This procedure is automated using the Downhill Simplex Method [5] for calculating the two parameters of the translation, namely the transposition in the x-axis, *Dx*, and the transposition in the y-axis, *Dy*. Mutual Information [6] is used as a measure of match to pre-register the images.

2. Distinctive point extraction

This step is important in order to automatically extract the candidate points of the reference image. These points must be the most distinctive points which possess the highest amount of information, when compared to their immediate neighborhood. In other words, as far as an intensity-based image is concerned, a pixel is labeled as a distinctive one, if its intensity significantly varies from that of its neighboring pixels. A neighborhood is defined as a circular area of radius r. In order to make the detection more robust, neighborhoods of pixels are compared instead of pixels alone. Therefore, for each pixel (x, y) of the reference image, its neighborhood of radius r is compared to the equally sized neighborhood of each pixel lying on a radius R around (x, y). This means that the digital circle of radius r around (x, y) is compared to all digital circles of radius r centered at $(x+k, y+l)$ with $k^2 + l^2 < R^2$. Usually, R is greater than r, but there are cases where the two radii could be equal. Whatever the case, their values play a key role to the quality of the registration product. Typical values for the radii are $R = 25$ and $r = 5$. In order to compare the neighborhoods in question, the absolute gray level difference is used as a similarity measure [7]. Thus, for each pixel of the reference image and for $k^2 + l^2 < R^2$ and $i^2 + j^2 \leq r^2$:

$$Sim((x, y), (x+k, y+l)) = \frac{1}{(G-1)N} \sum \left| I_R(x+i, y+j) - I_R(x+k+i, y+l+j) \right| \quad (1)$$

where G is the number of gray levels in the image and N is the number of pixels in the neighborhood of radius r. The distinctiveness of each pixel (x, y) is then determined by calculating the product of the similarity measures $Sim(\,)$ for all pixels $(x+k, y+l)$ with $k^2 + l^2 < R^2$. Having calculated a distinctiveness value for each pixel, we can re-arrange them in descending order, and hence select for example the $M = 500$ more distinctive feature points to work with. Those points usually accumulate along edges or, in general, around regions with high contrast fluctuation.

3. Definition of automatic correspondence

An automatic correspondence of the points extracted on the reference image is then obtained. According to this process, two different methods are used to define the correspondences: a template matching scheme and the proposed approach, which is a suitably revised version of the Center-based Inner Search algorithm. The two methods are presented analytically below.

A) Automatic Extraction of Corresponding Points Method

The Automatic Extraction of Corresponding Points scheme utilizes a template matching method to obtain correspondences [7]. In order to allocate the corresponding point of a point (x, y), a circular area of radius r from the reference image is propagated over a circular area of radius R from the floating image, which is centered at (x, y). As the template circulates over the designated area of the floating image, the differences between the template and the area underneath are recorded. Again, the similarity function defined in (1) can be used to assess those differences. In this case the area which minimizes the similarity function is assumed to be the neighborhood of the corresponding point. Hence, the center of that area is considered to be the corresponding point of (x, y) in the floating image. This particular technique prerequisites that $R \geq r$. In fact, for small R values, the search area is reduced and hence the likelihood of an erroneous corresponding point is increased. On the other hand, if R is very large, the search area is broadened, increasing the possibility for a search area far from point (x, y).

B) The Enhanced Hexagonal Center-based Inner Search Algorithm

This method is a modified version of the Center-Based Inner Search (CBIS) approach [8]. Like CBIS, the Enhanced Hexagonal Center-based Inner Search (EHCBIS) method estimates image motion in a predictive manner. The algorithm converges to an optimal set of corresponding points, through a repetitive process [8]. The general idea of EHCBIS is to fine-adjust an initial estimate of corresponding points by minimizing the intensity variations between the set of points extracted from I_R and the estimated set of corresponding points extracted from I'_F, the pre-registered float image. In particular, let $\mathbf{P}_n$ $(n = 1,2,...,M)$ denote an extracted distinctive point on the reference image with coordinates (x_n, y_n) and $\mathbf{P'}_n$ its corresponding point on the pre-registered float image, with coordinates (x'_n, y'_n). Initially, $x'_n = x_n$ and $y'_n = y_n$. Then, the intensity of $\mathbf{P}_n$ is compared to the intensity of those pixels of the float image that lie on the edge of a digital hexagon centered around $\mathbf{P'}_n$. The intensity variation is expressed as follows:

$$Iv(i, j; x_n, y_n, x'_n, y'_n) = \left| I_R(x_n, y_n) - I'_F(x'_n + i, y'_n + j) \right| \quad (2)$$

for $i = -2, -1, 1, 2$ and $j = -2, -1, 0, 1, 2$. Moreover, $I_R(x_n, y_n)$ is the intensity of $\mathbf{P}_n$ and $I'_F(x'_n, y'_n)$ is the intensity of $\mathbf{P'}_n$. The method is visually depicted in Fig. 2.

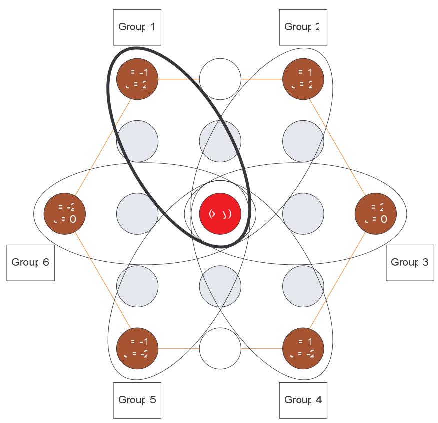


Fig. 2: Graphical representation of the EHCBIS group selection.

In our case, the hexagon was selected to be five pixels wide for simplicity. After calculating the intensity variations for all six groups, according to (2), the group with the smallest intensity variation is regarded as the one that includes the candidate corresponding point (gray circles in Fig. 2). For Groups 3 and 6, as they are illustrated in Fig. 2, there is only one candidate point, so it is assumed to be the new position of $\mathbf{P'}_n$. The rest of the groups include two candidate points. In such a case, the estimate is selected by considering the point closest to the group with the smallest intensity variation. If for example the candidate lies within Group 1 in Fig. 2, the intensity variations of Groups 2 and 6 have to be examined. The process recurs for every distinctive point extracted from the reference image. After all correspondences have been estimated, the entire scheme iterates, using the newly estimated correspondences, until the algorithm converges to an optimal set of corresponding points or until a fixed number of iterations is reached. An estimated point set is considered as an optimal one, if the average difference between the gray levels of the distinctive points and their corresponding points drops below a specified threshold $Td_{ave} = 5$. In this case, where a five pixel wide hexagon is used, the coordinates of the estimated corresponding points translate by one pixel at a time; thus avoiding massive leaps, which could lead to the detection of false correspondences.

4. Registration using geometrical transformations

The dental pairs are then registered using a geometrical transformation. A general two-dimensional (2D) affine transformation has been applied according to the following equation:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} a_1 & a_2 & dx \\ a_3 & a_4 & dy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \quad (3)$$

where a total of 6 parameters are required to define the affine transformation.

The parameters of the affine transformation are estimated using the corresponding points as defined by the two methods of the previous process. For both cases, the optimal values of the selected geometrical transformation parameters are obtained by Singular Value Decomposition (SVD) [5].

5. Registration results evaluation

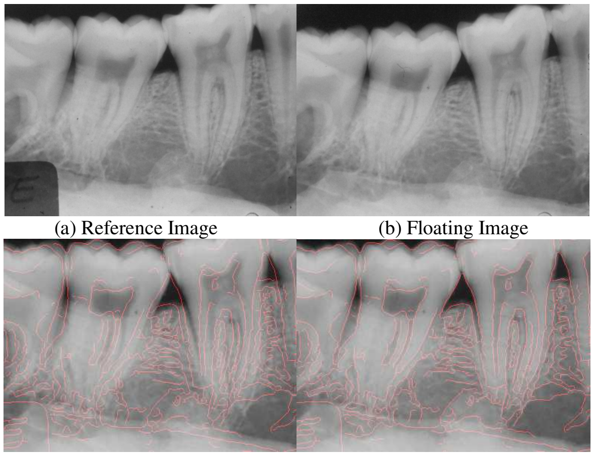
Qualitative evaluation of the two methods for automatic correspondence is performed by means of visual assessment of the registration results by experienced dentists. Quantitative evaluation of the two methods is performed using the root mean square difference (RMSD) [3] between the reference and the finally aligned image. The RMS difference is calculated as follows:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{N} \left(I_R(\vec{r}_i) - I_{GTR}(\vec{r}_i) \right)^2}{N}} \quad (4)$$

where the sum is calculated only over the N pixels belonging to the region of overlap of the reference (I_R) and the finally aligned image using the geometrical transformation (I_{GTR}). Generally, for the same image pair, the smaller the RMS difference the better the registration achieved.

III. Results

The dental images used in this work are from an *in vitro* study. A dry mandible was mounted on a device which permitted the object and the film to be rotated vertically and horizontally relative to the central part of the X-ray beam. The focus of the object and the object-to-film distance were kept constant at 40 cm and 0.5 cm, respectively. The radiographs were digitized with a flatscanner (Agfa Arcus II) producing 8-bit gray scale image files. The reference radiograph was taken with the central ray of the X-ray beam perpendicular to the long axes of the teeth as judged subjectively and with no resulting overlaps of adjacent tooth surfaces. Subsequent images were then obtained by moving the object either vertically or horizontally relative to the X-ray beam at 0º, 3º and 6º, respectively. Thus, a total of 24 dental pairs were finally produced. The data have included white background representing regions outside the film limits. Therefore, the spatial match has been restricted to cropped images excluding the undesired parts. The size of the cropped radiographs used in the study was 428×310 pixels.



(a) Reference Image (b) Floating Image

(c) Automatic Extraction of Corresponding Points (d) Enhanced Hexagonal Center-based Inner Search (EHCBIS)

Fig. 3: Registration results using the two correspondence methods.

Fig. 3 shows the registration results for a pair of radiographs selected from the study. Fig. 3a and b show the reference and the subsequent (floating) radiograph. Fig. 3c and d show the registered images using the two correspondence methods, respectively as well as the edges of the reference image superposed, as detected by applying a 3×3 Sobel gradient filter. It can be seen that the proposed method for automatic correspondence produced better results compared to the other method.

The evaluation of the two automatic correspondence methods has been assessed by estimating the RMS difference between the reference and the final aligned image. The results are presented in Table I using the affine transform. From Table I, it is evident that the proposed modified automatic correspondence method outperforms the other method for the vast majority of the radiographic pairs in terms of the RMS difference. In particular, in 23 out of the 24 total tests, the EHCBIS algorithm performed better than the well-established method. Moreover, the mean RMS difference over all 24 dental pairs is greatly improved using the EHCBIS algorithm (5.764) against the Automatic Extraction of Corresponding Points technique (9.561). As far as the execution time is concerned, the proposed approach marginally leads by 1.332 seconds on average. Finally, the robustness of the EHCBIS algorithm is proven by its relatively low standard deviation of the RMS difference (1.009) against the compared method (1.895), as shown in Table I.

IV. Conclusions

In this paper, a modified version of CBIS, the Enhanced Hexagonal Center-based Inner Search (EHCBIS) algorithm, is proposed to define automatic correspondence towards point-based registration of dental radiographs. The algorithm was compared in terms of registration accuracy against the well-known Automatic Extraction of Corresponding Points method and the results obtained showed advantageous performance of the EHCBIS algorithm for the majority of image pairs.

TABLE I
PERFORMANCE OF THE TWO AUTOMATIC CORRESPONDENCE METHODS IN TERMS OF REGISTRATION ACCURACY USING THE RMS DIFFERENCE

Dental Image Pairs	***Automatic Extraction of Corresponding Points***	***Enhanced Hexagonal Center-based Inner Search***
Pair-1	9.874	6.400
Pair-2	10.951	5.825
Pair-3	9.514	6.337
Pair-4	10.730	6.100
Pair-5	8.892	7.411
Pair-6	10.608	5.008
Pair-7	11.200	6.611
Pair-8	4.503	4.514
Pair-9	6.821	5.264
Pair-10	11.502	4.864
Pair-11	9.747	7.229
Pair-12	10.320	3.905
Pair-13	10.478	4.905
Pair-14	11.857	5.729
Pair-15	7.175	5.123
Pair-16	8.799	4.442
Pair-17	6.084	4.446
Pair-18	10.459	5.416
Pair-19	12.463	6.599
Pair-20	9.802	7.382
Pair-21	9.427	5.548
Pair-22	7.874	7.124
Pair-23	10.398	5.775
Pair-24	9.991	6.392
Mean	**9.561**	**5.764**
Std. Dev.	**1.895**	**1.009**
Ex. Time	**61.292 sec**	**59.960 sec**

References

[1] A. Mol, and S.M. Dunn, "The performance of projective standardization for digital subtraction radiography", *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.*, vol. 96, pp. 373-382, 2003.

[2] T.M. Lehmann, H-G Gröndahl, and D.K. Benn, "Computer-based registration for digital subtraction in dental radiology", *Dentomaxillofac. Radiology*, vol. 29, pp. 323-346, 2000.

[3] D.C. Yoon, "A new method for the automated alignment of dental radiographs for digital subtraction radiography", *Dentomaxillofac. Radiology*, vol. 29, pp. 11-19, 2000.

[4] E.I. Zacharaki, G.K. Matsopoulos, P.A. Asvestas, K. Gröndahl, and H-G. Gröndahl, "A digital subtraction radiography scheme based on automatic multiresolution registration", *Dentomaxillofac. Radiology*, vol. 33, pp. 1-14, 2004.

[5] W.H. Press, S.A. Teukolsky, W.T. Vetterling and B.P. Flannery, "Numerical recipes in C: The art of scientific computing, 1988-1992.

[6] P. Viola and W.M. Wells III, Alignment by maximization of mutual information, International journal of computer vision, vol. 24, pp. 137-154, 1997

[7] B. Likar and F. Pernus, "Automatic extraction of corresponding points for the registration of medical images", *Medical Physics*, vol. 26, pp. 1678–1686, 1999.

[8] C. Zhu, X. Lin, L-P. Chau and L-M. Po, "Enhanced hexagonal search for fast block motion estimation", IEEE Transactions on Circuit and Systems for Video Technology, vol. 14, pp. 1210-1214, 2004.