Medical Image Registration Using Phase-Only Correlation for Distorted Dental Radiographs

Koichi Ito[1], Takafumi Aoki[1], Eiko Kosuge[2], Ryota Kawamata[2] and Isamu Kashima[2]
[1] Graduate School of Information Sciences, Tohoku University
Sendai-shi 980-8579, Japan
E-mail: ito@aoki.ecei.tohoku.ac.jp
[2] Department of Oral and Maxillofacial Radiology, Kanagawa Dental College,
82, Inaoka, Yokosuka-shi, 238-8580 Japan

Abstract

This paper proposes an efficient dental radiograph registration algorithm using Phase-Only Correlation (POC). The use of phase components in 2D (two-dimensional) discrete Fourier transforms of dental radiograph images makes it possible to achieve highly robust image registration and recognition. The proposed algorithm finds correspondence points between two images using the sub-pixel correspondence search using POC and corrects nonlinear distortion based on the Thin-Plate Spline (TPS) model. Experimental evaluation using a dental radiograph database indicates that the proposed algorithm exhibits efficient recognition performance even for distorted radiographs.

1 Introduction

Dental radiographs have been used for detecting small changes of internal bone structures, monitoring disease progression, planning and guiding dental treatment, etc. For these purposes, radiographs acquired from subjects over short or long periods of time have to be compared after image registration [3]. The accuracy of dental radiograph registration is important for an accurate Computer-Aided Diagnosis (CAD).

There is nonlinear distortion between dental radiographs captured from the same person, since the positions of the X-ray tube and the imaging plate are set manually by a dentist. There are some works on dental radiograph registration [7, 6, 9]. The reported algorithms deal with only rigid body transformation caused by positional relationship between the X-ray tube and the imaging plate. For accurate dental radiograph registration, nonlinear distortion should be corrected.

Addressing this problem, we propose an efficient algorithm for dental radiograph image registration using Phase-Only Correlation (POC). The proposed algorithm employs (i) high-accuracy image matching technique using POC for rotation and displacement alignment and (ii) sub-pixel correspondence search technique using POC for parameter estimation of Thin-Plate Spline (TPS) model. The use of POC technique makes it possible to achieve fully automatic and high-accuracy image registration even for distorted radiographs. Experimental evaluation using a set of dental radiographs taken before and after dental treatment demonstrates efficient registration performance of the proposed algorithm.

2 Phase-Only Correlation

2.1 Phase-only correlation function

We introduce the principle of a Phase-Only Correlation (POC) function (which is sometimes called the "phase-correlation function") [5, 12, 13].

Consider two $N_1 \times N_2$ images, $f(n_1, n_2)$ and $g(n_1, n_2)$, where we assume that the index ranges are $n_1 = -M_1, \cdots, M_1$ ($M_1 > 0$) and $n_2 = -M_2, \cdots, M_2$ ($M_2 > 0$) for mathematical simplicity, and hence $N_1 = 2M_1 + 1$ and $N_2 = 2M_2 + 1$. Let $F(k_1, k_2)$ and $G(k_1, k_2)$ denote the 2D DFTs of the two images. $F(k_1, k_2)$ is given by

$$\begin{aligned} F(k_1, k_2) &= \sum_{n_1, n_2} f(n_1, n_2) W_{N_1}^{k_1 n_1} W_{N_2}^{k_2 n_2} \\ &= A_F(k_1, k_2) e^{j\theta_F(k_1, k_2)}, \end{aligned} \quad (1)$$

where $k_1 = -M_1, \cdots, M_1$, $k_2 = -M_2, \cdots, M_2$, $W_{N_1} = e^{-j\frac{2\pi}{N_1}}$, $W_{N_2} = e^{-j\frac{2\pi}{N_2}}$, and $\sum_{n_1, n_2}$ denotes

978-1-4244-2175-6/08/$25.00 ©2008 IEEE

$\sum_{n_1=-M_1}^{M_1}\sum_{n_2=-M_2}^{M_2}$. $A_F(k_1,k_2)$ is amplitude and $\theta_F(k_1,k_2)$ is phase. $G(k_1,k_2)$ is defined in the same way. The cross-phase spectrum $R_{FG}(k_1,k_2)$ is given by

$$R_{FG}(k_1,k_2) = \frac{F(k_1,k_2)\overline{G(k_1,k_2)}}{|F(k_1,k_2)\overline{G(k_1,k_2)}|} = e^{j\theta(k_1,k_2)}, \quad (2)$$

where $\overline{G(k_1,k_2)}$ is the complex conjugate of $G(k_1,k_2)$ and $\theta(k_1,k_2)$ denotes the phase difference $\theta_F(k_1,k_2)-\theta_G(k_1,k_2)$. The POC function $r_{fg}(n_1,n_2)$ is the 2D Inverse DFT (2D IDFT) of $R_{FG}(k_1,k_2)$ and is given by

$$r_{fg}(n_1,n_2) = \frac{1}{N_1N_2}\sum_{k_1,k_2} R_{FG}(k_1,k_2) W_{N_1}^{-k_1n_1}W_{N_2}^{-k_2n_2}, \quad (3)$$

where $\sum_{k_1,k_2}$ denotes $\sum_{k_1=-M_1}^{M_1}\sum_{k_2=-M_2}^{M_2}$. When two images are similar, their POC function gives a distinct sharp peak. When two images are not similar, the peak drops significantly. The height of the peak gives a good similarity measure for image matching, and the location of the peak shows the translational displacement between the images.

2.2 Phase-based image matching

Listed below are key features of the phase-based image matching using POC function, which are used in this paper.

(A) Translational displacement estimation

We have proposed a high-accuracy translational displacement estimation method, which employs (i) an analytical function fitting technique to estimate the sub-pixel position of the correlation peak, (ii) a windowing technique to eliminate the effect of periodicity in 2D DFT, and (iii) a spectrum weighting technique to reduce the effect of aliasing and noise [12].

(B) Sub-pixel correspondence search

We have developed an efficient method of sub-pixel correspondence matching, which employs (i) a coarse-to-fine strategy using image pyramids for robust correspondence search and (ii) a sub-pixel window alignment technique for finding a pair of corresponding points with sub-pixel displacement accuracy [8].

(C) Rotation angle estimation

We have extended the POC-based image matching to the registration for images including translation, rotation and scaling simultaneously [12]. In this paper, we focus on the rotation alignment using the POC-based image matching. We employ the polar mapping of the amplitude spectrum to transform the image rotation into image translation. The rotation angle is estimated by detecting the corresponding translational displacements by the above technique.

(D) Similarity evaluation

We have developed a similarity evaluation technique using Band-Limited Phase-Only Correlation (BLPOC) function [4]. The idea to improve the similarity evaluation performance is to eliminate meaningless high frequency components in the calculation of cross-phase spectrum R_{FG} depending on the inherent frequency components of images.

3 Dental Radiograph Registration Algorithm

In this section, we present a dental radiograph registration algorithm using POC. The proposed algorithm consists of 4 steps: (i) image enhancement, (ii) rotation and displacement alignment, (iii) distortion correction and (iv) matching.

(i) Image enhancement

First step is the enhancement of radiograph image to allow accurate radiograph image processing, since these images are often blurred due to substantial noise, poor lighting, etc. In our proposed algorithm, we employ the contrast enhancement techniques using local area contrast enhancement [10] and morphological filters [11]. Figure 1 (b) shows the enhanced images, $f_e(n_1,n_2)$ and $g_e(n_1,n_2)$, of the registered image $f(n_1,n_2)$ and the input image $g(n_1,n_2)$, respectively.

(ii) Rotation and displacement alignment

We normalize rotation and displacement between the enhanced images $f_e(n_1,n_2)$ and $g_e(n_1,n_2)$. We first estimate the rotation angle θ by using POC technique described in Sec 2.2 (C). Using θ, we obtain a rotation-normalized image $g_{e\theta}(n_1,n_2)$. Then, we align the translational displacement between $f_e(n_1,n_2)$ and $g_{e\theta}(n_1,n_2)$ using the peak location of the BLPOC function. Thus, we have normalized versions of the registered image and the input image as shown in Fig. 1 (c), which are denoted by $f'(n_1,n_2)$ and $g'(n_1,n_2)$.

(iii) Distortion correction

We correct the projective distortion between two images. We first obtain the landmark points in $f'(n_1,n_2)$ using the Harris corner detector [2] as shown in Fig. 2 (a). Next, we find the points in $g'(n_1,n_2)$ which correspond to the feature points in $f'(n_1,n_2)$ using the sub-pixel correspondence search using POC technique as shown in Fig. 2 (b). According to correspondence between $f'(n_1,n_2)$ and $g'(n_1,n_2)$, we estimate parameters of the non-rigid body transformation, where we employ This-Plate Spline (TPS) model [1] to correct

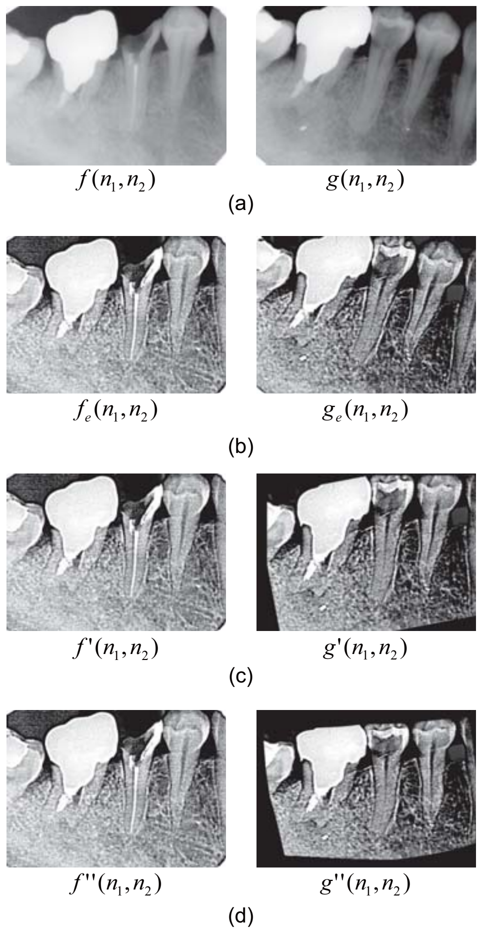

Figure 1. Example of dental radiograph registration: (a) the registered image and the input image, (b) the enhanced images, (c) the normalized images and (d) images after distortion correction.

nonlinear distortion. Figure 1 (e) shows the distortion-corrected images $f''(n_1, n_2)$ and $g''(n_1, n_2)$.

(iv) Matching

This step is for quantitative evaluation of the proposed algorithm. The overlapped region of the two images $f''(n_1, n_2)$ and $g''(n_1, n_2)$ to improve the accuracy of dental radiograph matching, since the non-overlapped areas of the two images become the uncorrelated noise components in the BLPOC function. In order to detect the effective areas in $f''(n_1, n_2)$ and $g''(n_1, n_2)$, we examine the n_1-axis projection and the n_2-axis projection of pixel values. To evaluate the matching score, we calculate the BLPOC function between two images $f''(n_1, n_2)$ and $g''(n_1, n_2)$. The matching score is the highest peak value of the BLPOC function.

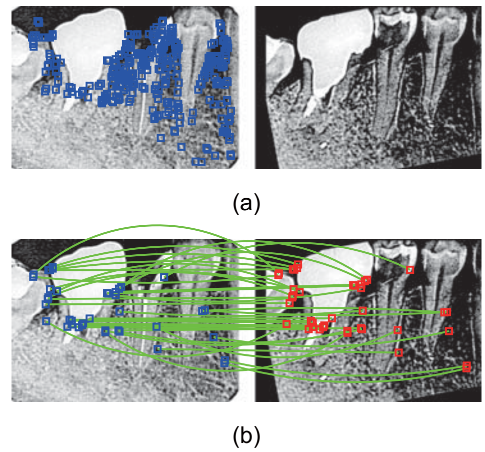

Figure 2. Example of distortion correction: (a) normalized images and landmark points on the registered image and (b) corresponding points between images.

4 Experiments

This section describes a set of experiments using the dental radiograph database for evaluating registration performance of the proposed algorithm. In this experiment, we use dental radiographs taken before and after dental treatment. Our database consists of 500 images (367×485 pixels) with 250 subjects and 2 different images of each dental radiograph.

We compare three algorithms: the proposed registration algorithm without distortion correction (A), with distortion correction using projective transformation (B) and with distortion correction using TPS transformation (C). The registration performance of the proposed algorithm is evaluated by identifying the subjects in order to perform the quantitative evaluation. In this experiment, 250 subjects after dental treatment are matched to the 250 subjects before dental treatment. Figure 3 shows the cumulative match curve of the proposed algorithm, which is used for evaluating the performance of the identification system. Using the top-1 radiograph, the recognition accuracy of (C) is 82.8% (=207/250) while that of (A) is 69.6% (=174/250) and that of (B) is 76.8% (=192/250). Figure 4 shows examples of registration results and the subtraction image. As is observed in this experimental result, the proposed algorithm is useful for matching low-quality and distorted dental radiographs.

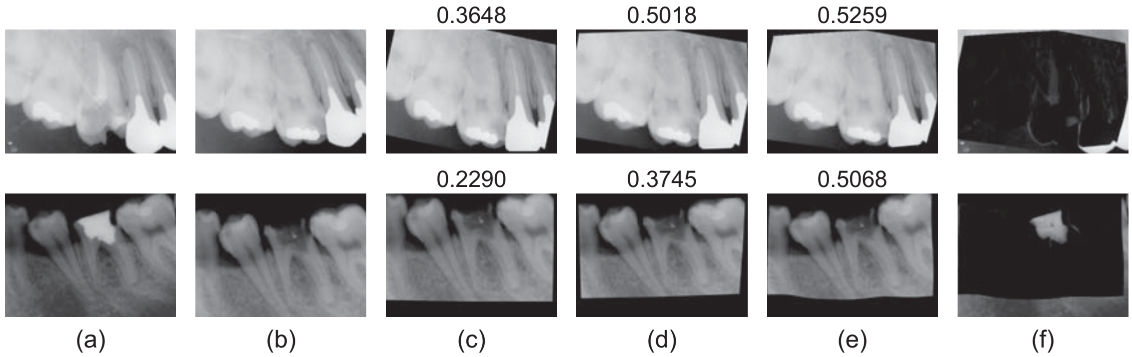

Figure 4. Examples of registration results: (a) registered image $f(n_1, n_2)$, (b) input image $g(n_1, n_2)$, (c) aligned image using the algorithm (A), (d) aligned image using the algorithm (B), (e) aligned image using the algorithm (C) and (f) subtraction image between (a) and (e) (the values on images (c), (d) and (e) show matching scores).

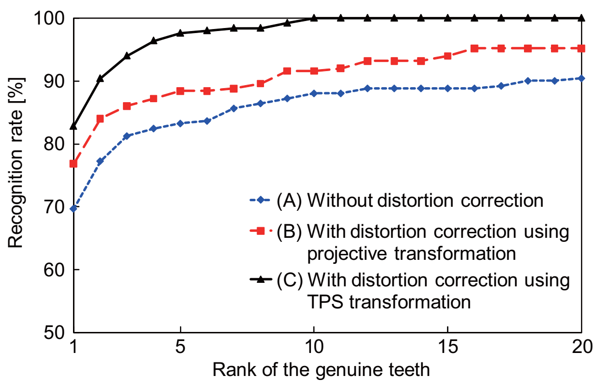

Figure 3. Cumulative match curve.

5 Conclusion

This paper proposed a medical image registration algorithm using Phase-Only Correlation for distorted dental radiographs. Experimental evaluation demonstrates efficient performance of our proposed algorithm. For our future work, we will develop a Computer-Aided Diagnosis (CAD) system for dental treatment using the proposed algorithm.

References

[1] F. L. Bookstein. Principal warps: Thin-plate splines and the decomposition of deformations. *IEEE Trans. Pattern Anal. Machine Intell.*, 16(6):567–585, June 1989.

[2] C. Harris and M. Stephens. A combined corner and edge detector. *Proc. The Fourth Alvey Vision Conference*, pages 147–151, 1988.

[3] D. L. G. Hill, P. G. Batchelor, M. Holden, and D. J. Hawkes. Medical image registration. *Phys. Med. Biol.*, 46:R1–R45, 2001.

[4] K. Ito, H. Nakajima, K. Kobayashi, T. Aoki, and T. Higuchi. A fingerprint matching algorithm using phase-only correlation. *IEICE Trans. Fundamentals*, E87-A(3):682–691, Mar. 2004.

[5] C. D. Kuglin and D. C. Hines. The phase correlation image alignment method. *Proc. Int. Conf. Cybernetics and Society*, pages 163–165, 1975.

[6] T. M. Lehmann, H.-G. Gróndahl, and D. K. Benn. Computer-based registration for digital subtraction in dental radiology. *Dentomaxillofacial Radiology*, 29:323–346, 2000.

[7] T. M. Lehmann, K. Gróndahl, H.-G. Gróndahl, W. Schmitt, and K. Spitzer. Observer-independent registration of perspective projection prior to substraction of in vivo radiographs. *Dentomaxillofacial Radiology*, 27:140–150, 1998.

[8] M. A. Muquit, T. Shibahara, and T. Aoki. A high-accuracy passive 3d measurement system using phase-based image matching. *IEICE Trans. Fundamentals*, E89-A(3):686–697, Mar. 2006.

[9] A. Nikaido, K. Ito, T. Aoki, E. Kosuge, and R. Kawamata. A phase-based image registration algorithm for dental radiograph identification. *Proc. the 2007 IEEE Int. Conf. Image Processing*, pages VI–229–VI–232, Sept. 2007.

[10] G. X. Ritter and J. N. Wilson. *Handbook of Computer Vision Algorithms in Image Algebra*. CRC Press, 1996.

[11] P. Soille. *Morphological Image Analysis*. Springer, 1999.

[12] K. Takita, T. Aoki, Y. Sasaki, T. Higuchi, and K. Kobayashi. High-accuracy subpixel image registration based on phase-only correlation. *IEICE Trans. Fundamentals*, E86-A(8):1925–1934, Aug. 2003.

[13] K. Takita, M. A. Muquit, T. Aoki, and T. Higuchi. A sub-pixel correspondence search technique for computer vision applications. *IEICE Trans. Fundamentals*, E87-A(8):1913–1923, Aug. 2004.