Proceedings of the 2005 IEEE
Engineering in Medicine and Biology 27th Annual Conference
Shanghai, China, September 1-4, 2005

Image Registration in Intra-oral Radiography

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Abstract: Image registration is one of the image processing methods which is widely used in computer vision, pattern recognition, and medical imaging. In digital subtraction radiography, image registration is one of the important prerequisites to match the reference and subsequent images. In this paper, we propose an automatic non-rigid registration method namely curvature-based registration that relies on a curvature based penalizing term and its application on dental radiography. The regularizing term of this intensity-based registration approach provides affine linear transformation so that pre-registration step is no longer necessary. This leads to faster and more reliable solutions. The implementation of this approach is based on the numerical solution of the underlying Euler-Lagrange equations. In addition, a comparison between this algorithm and Linear Alignment Method (LAM) with 20 image pairs is presented.

Keywords: *Image registration, digital subtraction radiography, Euler-Lagrange equations.*

I. Introduction

Image registration is a useful technique in image processing applied in the areas such as geophysics, computer vision and medical image analysis [1,4-5]. Particularly in medical imaging, it is very important for a large number of applications such as clinical diagnostic, planning treatment, guiding surgery and studying disease progression. In this paper, we focus on medical image registration and specifically on dental application.

Digital subtraction radiography (DSR) is a useful technique introduced by Ruttimann *el al*. [6-7] for diagnosing subtle changes in radiographic density by longitudinal evaluation of serial radiographs of the same anatomical region. DSR has become important for early detection of disease and for measurement of disease progression. It has been used for the diagnosis of dental caries, destructive periodontal diseases and alveolar bone changes. Visual interpretation of intra-oral radiographs has been shown to be of limited diagnostic value for the early detection of subtle bone changes. With advances in the development of computer technology, DSR is developed into practical approach in dentistry to assess the differences between intra-oral radiographs. Image registration is one of the crucial prerequisites for DSR in order to obtain an accurate subtracted image. However, misalignments and bending mismatches easily arises in image alignment which will affect the accuracy of the subtracted image and diagnosis [10]. Most of DSR methods currently used are based on manual registration techniques. The landmarks or reference points are marked manually on both images undergo registration or only one of them in these manual registration methods. Therefore, the result and quality of the registration is affected by the degree of precision in positioning landmarks and the observer experience placing the landmarks [8].

In this paper, we approach a new non-rigid intensity-based image registration method called curvature registration which was developed by Fishcher *et al* [1-3]. This method is fully automatic and accurate without using the manual selection of reference points. The key of image matching in this method is minimized a suitable distance measure subject to a curvature-based constraint, and the computation of displacement is dependent on the intensity of image pairs.

II. Theory of Curvature Registration

It is given two images called reference image R and a template image T. The objective of image registration is to determine a transformation of T onto R such that the template image T aligns onto the reference image R absolutely. For a particular spatial point $\mathbf{x} \in \Omega \subset \Re$ on T, the value ***T(x)*** is the intensity at **x.** It is determined a displacement field $u: \Omega \to \Omega$ such that $T(x-u(x))$ is very similar to $R(x)$ or ideally $T(x-u(x)) = R(x)$. The problem is how to find this displacement field *u*, in two dimensions, (u_1, u_2) to obtain a satisfactory registration result.

In order to find the desired displacement *u*, we need to minimize the following function shown in equation (1).

$$\Im[u] = D[R,T;u] + \alpha\, S^{curv}[u] \qquad (1)$$

where

$$D[R,T;u] = \frac{1}{2}\int_{\Omega} (T(x-u(x)) - R(x))^2\, dx \qquad (2)$$

$$S^{\mathrm{curv}}[u] = \frac{1}{2}\sum_{l=1}^{d} \int (\Delta u_l)^2\, dx \qquad (3)$$

D[R, T; u] represents the sum of square difference (SSD) distance measure and $S^{curv}[u]$ determines the smoothness of the displacement *u*. The second term $S^{curv}[u]$ is important since it can solve the problems during transformation such as cracks, foldings or other useless deformations. One of the reasons for choosing $S^{curv}[u]$ is that it has a non-trivial kernel containing affine linear transformations. The parameter α may be used to control the strength of the smoothness of the displacement versus the similarity of the images.

The minimization of equation (1) is characterized by the following Euler-Lagrange equations

$$f(x,u(x))+\alpha\Delta^2 u=0, \qquad x\in\Omega \qquad (4)$$

where

$f(x,u(x))=(R(x)-T(x-u(x)))\cdot\nabla T(x-u(x))$ $f(x,u(x))$ is the force field which is the Gateaux derivative of the distance measure D and $\Delta^2 u$ is the Gateaux derivative of the regularizing term S^{curv}. In equation (4), a suitable value of displacement u can be achieved.

Introducing an artificial time t, making the displacement u time dependent, $u = u(x,t)$ and setting $u^k(x)=u(x,k\tau)$, where τ denotes a fixed time-step, a semi-implicit method for the time-dependent PDE is shown in equation (5).

$$\partial_t u^{k+1}(x,t)+\alpha\Delta^2 u^{k+1}(x)=f(x,u^k(x)) \qquad (5)$$

To apply a finite different discrimination adapted to the geometry of the domain Ω, this approach results in a system of linear equations,

$$(I_N+\tau\alpha\Delta^2)U^{k+1}=U^k+\tau F^k \qquad (6)$$

where N denotes the number of pixel, I_N is the unit matrix, τ is the time step (Δt) and U^k and F^k represent the values of displacement u and force f respectively. $\boldsymbol{U^{k+1}}$ represents the displacement on the grid in the next step.

Eigendecomposition is then used to solve for $\boldsymbol{U^{k+1}}$ and the eigenvalue λ of Δ^2 is found to be $4(\cos\frac{\pi x}{a}+\cos\frac{\pi x}{b}-2)^2$. U^{k+1} can immediately be computed by obtaining the eigenvalue λ and performing the discrete cosine transformation (DCT). U^{k+1} can be found by the three steps shown as follows:

1. Find the DCT of $U^k+\tau F$, such that G = DCT $U^k+\tau F$
2. Divide G by $(1+\tau\alpha\lambda)$ pointwise, such that H = G $(I_N+\tau\alpha\lambda)^{-1}$
3. Do inverse DCT on H, such that U^{k+1} = iDCT(H)

III. Results and Discussion

1. Experiments on Intra-oral radiograph

The performance of the curvature registration is evaluated using a pair of Intra-oral radiographs. Figure 1 (a) and (c) show the reference R and the template T respectively, and it can be observed that there is bending error existed in the images. The mismatched area between R and T is shown in Figure 1 (d). Due to the bending error, α should be set to a small value so as to allow template to undergo a large deformation and then align on the reference. Here, α is chosen to be 10 while τ is set to 2, to keep the time step low and to prevent the deformation from vacillating too vigorously. With 250 iterations, the satisfactory registration result is shown in Figure 1 (b) whereas the difference $|R-T_{250}|$ is shown in Figure 1 (e). Figure 1 (f) shows the relative error of the two dental radiographs decreased to approximately less than 25%, that means over 75% of mismatched area has been eliminated.

2. Comparison of curvature registration and LAM

Linear alignment method (LAM) is first present by Leung *et al* [10-11] which is a semi-automatic image alignment algorithm using linear transformation. The disadvantage of this method is limited to linear transformation only. In this section, our approach and LAM is evaluated based on 20 set of intra-oral radiographs.

Intra-oral radiographs are taken from the same lower molar region in a human dry skull with each of three exposure times (0.16s, 0.18s, 0.22s) [6]. In order to have standardized periapical radiographs for subtraction, a custom-made acrylic bite block attached to a Rinn XCP film holder was made. The X-ray machine's long cone was modified so as to produce a rigid attachment of the bite block to the cone. Hence, the angulations between the X-ray source, the object and the film could be reproducible. All periapical radiographs were taken using the paralleling technique with the same X-ray machine at the same setting, 70kV, 15mV. All films were developed with an automatic developing machine and in a batch to reduce variability during the development process.

Twenty pairs of images are selected for this experiment. One is to be the reference R and the other is the template T for each pair, which is shown in Figure 2. Then, curvature-based registration method is performed on these twenty sets of images so twenty registered template T_{curv} are produced. Then three regions of interest (ROIs), refer to Figure 3, are selected and the computer-assisted densitometric image analysis (CADIA) [9] values are calculated to determine correlations between the CADIA values and the actual bone mass change. Since R and T are taken from the same human dry skull at the same time, so that the bone mass of the two radiographs should be the same. In the subtraction radiography, CADIA value should be a zero or below the threshold respectively as there is no bone change.

Figure 4 (a) and (b) are shown the result of the subtraction radiography using LAM and curvature registration respectively. The bottom right hand corner of (a) and (b) reveal the difference between the pixel values of two images. The green color denotes no change in pixel values that means the net change in bone mass is zero. The positive pixels in red and negative pixels in blue represent bone gain and bone loss respectively.

In order to investigate whether the error percentage of curvature registration is significantly lower than that of linear alignment method, a t-test is conducted for the three regions. For Cadia1, the derived t value from the statistics is 3.983, exceeds the tabled critical t value of 2.093 at level of significance = 0.05 with df=19. Thus, the mean of percentage error by using the curvature registration is significantly lower than the mean of percentage error by using the LAM in this region. Similarly, the derived t values of Cadia2 and Cadia3 are 4.105 and 5.214 respectively.

From the above consistent statistical results, the derived t values of the three regions all exceed the tabled critical t value of 2.093. Thus, this experiment demonstrates that the percentage error of radiography subtraction making use of curvature registration method is significantly lower than that of linear alignment method. In other words, the curvature registration method appears to work more effectively than LAM.

In this experiment, due to the radiographs were taken from a human dry skull, less force is exerted by the musculature of the oral cavity, many of the radiographic image pairs have only a small degree of bending error and it can be used the linear transformation to obtain the good result. However, in real-life, bending error has been existed too significant in intra-oral radiographs. Linear alignment method cannot satisfy to align this kind of images. For example, in Figure 5 (a), the template image has been moved to match with the reference image but it is impossible to eliminate the mismatched area using the linear alignment method. In such cases, curvature registration method is very useful, α can be set to a small value to allow the template to undergo a non-linear deformation so as to align well on the reference image. The subtracted image of the reference R and the registered template T_{150} is shown in Figure 5 (b).

IV. Conclusion

The curvature image registration method has been presented in this paper. It shows that it is very efficient and reliable for automatic registration of different Intra-oral radiographs. Also, from the comparison with LAM, our approach obtains lower percentage error than the LAM.

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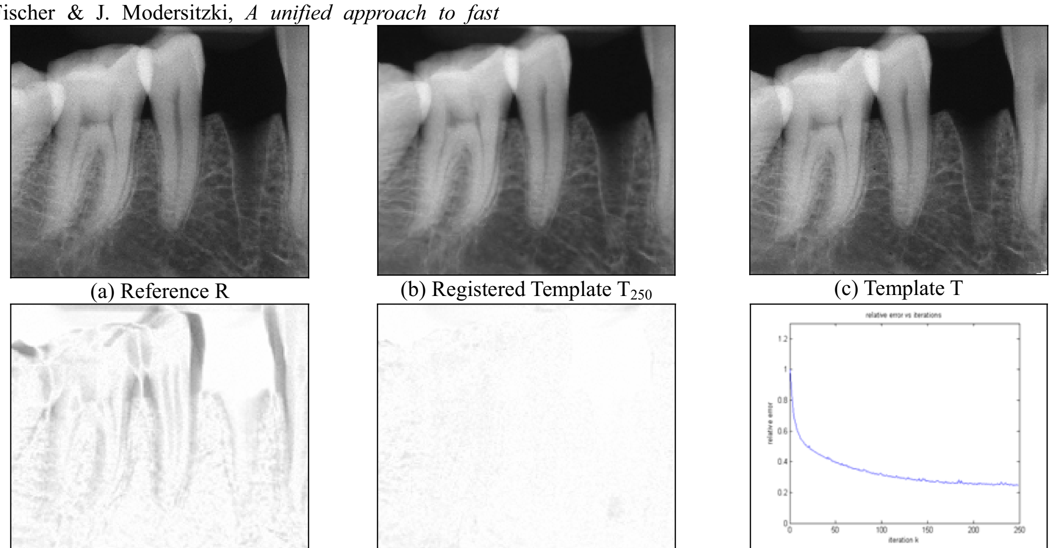
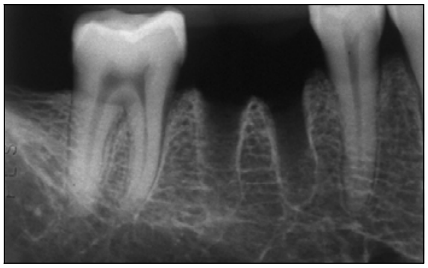


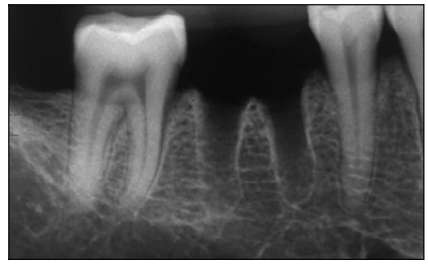
(a) Reference R　(b) Registered Template T_{250}　(c) Template T

(d) |R-T|　(e) $|R-T_{250}|$　(f) $|R-T_k|/|R-T|$

Figure 1. Curvature registration of human teeth X-ray images, α=10, τ=2, 250 iterations: (a) reference R, (b) registered template T_{250}, (c) template T, (d) difference |R-T|, (e) difference $|R-T_{250}|$ and (f) $|R-T_k|/|R-T|$ against number of iterations 250



(a) Reference R



(b) Template T

Figure 2 (a) Reference R, (b) template T

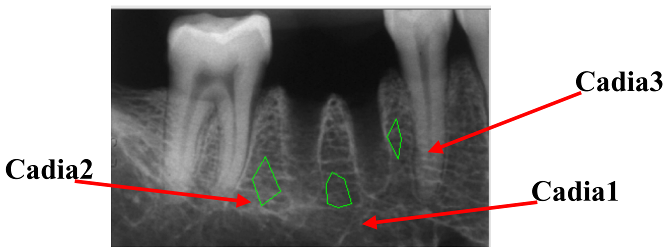
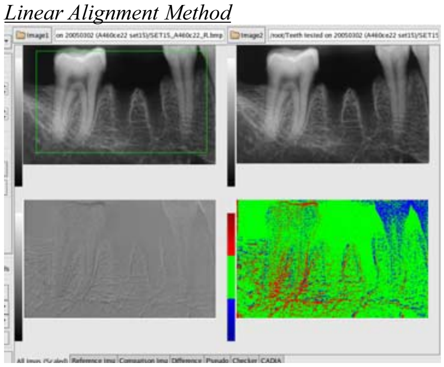


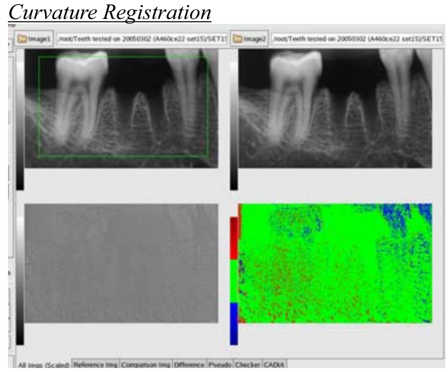
Figure 3 Three regions of interest: cadia1, cadia2 and cadia3

<u>*Linear Alignment Method*</u>



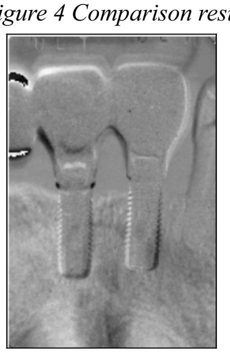
(a) After normalization, LEFT TOP: reference R, RIGHT TOP: aligned template T_{LAM}, BOTTOM: subtracted image of R and T_{LAM}

<u>*Curvature Registration*</u>

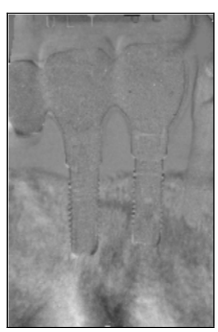


(b) After normalization, LEFT TOP: reference R, RIGHT TOP: registered template T_{curv}, BOTTOM: subtracted image of R and T_{curv}

Figure 4 Comparison results between LAM and curvature registration



(a) Subtracted image $|R-T_{LAM}|$



(b) Subtracted image $|R-T_{curv}|$

Figure 5. Subtracted images of implantation teeth