IMAGE REGISTRATION BASED ON LIFTING PROCESS AND GENETIC OPTIMIZATION: AN APPLICATION TO DENTAL IMAGING

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Abstract

In this paper, a new method for the registration of unimodal 2-D medical images is presented. The proposed method can be dealt with as an object-based registration method without imposing the often limiting prerequisite of segmentation in order to detect the boundary of the object of interest. This is achieved by augmenting the dimensionality of the problem from two-dimensional gray scaling matching to three-dimensional surface matching using the process of lifting in combination with an existing scheme for surface matching. The pseudo-three-dimensional transformation that matches the lifted images incorporates some advantageous characteristics in comparison with the simple two-dimensional affine transformation: Automatic anisotropic correction of brightness-contrast differences and introduction of some non-affine (projective) effects that very often are needed when matching radiographic modalities.

Key Words

Dental, Registration, Lifting, Genetic, Optimization, Decimation

1. Introduction

The possibility of storing a number of pre- and post-treatment digital radiographic images of the same patient imposes the problem of spatial alignment or equivalently registration of these images. By registering those dental images, the specialist can then perform any quantitative comparisons, concerning the evolution of abnormalities (cysts, tooth decay etc.) or healing processes, as well as the assessment of the effectiveness of the therapeutic scheme (implants, root canal surgery etc.). One of the most useful techniques, as well as challenging problems, is the combination, or fusion of information from two radiographic images from the same patient. A prerequisite for the image fusion is the registration, or spatial alignment of the two images, so that the same anatomical structures coincide on both images.

In general, different images are misaligned because of geometric distortions caused by: patient movements, imaging system geometric configurations (X-ray beam and CCD sensor in relative to the target tissue), physiological movements (respiration, heart beat) and development of abnormalities. It has been successfully applied to register CT, MRI, SPECT and PET data from [1].

The process of image registration can be formulated as a problem of optimizing a function that quantifies the match between the original and the transformed image [2]. Several image features have been used for the matching process, depending on the modalities used, the specific application and the implementation of the transformation, such as markers, landmarks, surfaces or volumes of interest. Registering dental images is a tedious process since the identification of common points between the two images is sometimes a difficult task. Moreover, the lack of characteristic edges of the radiographic images cannot be used as a prerequisite for the registration, as it is successfully used in other applications [2].

In this paper an automatic registration method for registering unimodal two-dimensional images is proposed, with application to dental radiograhy. This method combines the advantages of traditional three dimensional surface registration methods without requiring the existence of initial edge detection or other kind of segmentation. The surfaces to be matched are straight forward calculated with the process of lifting. The computational bargain of the dimensionality augmentation is balanced with the introduction of a more flexible transformation that can handle some non – affine cases and some initial settings distortions.

2. Materials and Methods

2.1 Data Acquisition

Dental X-ray images were acquired using an X-ray dental system. The images were digitized using a Panasonic digital camera with a CCD sensor and driven on a dedicated PC for further processing. The developed software is capable of displaying, processing and manipulating dental images.

2.2 Description of the Proposed Scheme

The new automatic registration method is based on a novel assembly of algorithms, which ultimately offers increased degree of automation by minimizing the need for user intervention. Initially, the two images (one corresponding to the reference radiography and the other to the transformed or floating radiography) are transformed from two-dimensional gray scale into three-dimensional binary images using the process of lifting [3].

The process of lifting is a transform *L* that converts a two-dimensional gray scene *(V, f)* into a three-dimensional binary scene $(V_L,, f_L)$ as follows: $V_L=V \times M$ where $M = \{l, l+1, \dots, h-1, h\}$, *l* and *h* being the minimum and maximum pixel intensities in *(V, f)*:

For all $\langle v_1, v_2, \dots, v_n \rangle \in V$ and $m \in M$,

$$f_l\left(\langle v_1, v_2, \dots, v_n, m \rangle\right) = 1 \, iff \;\; f\left(\langle v_1, v_2, \dots v_n \rangle\right) \geq m,$$

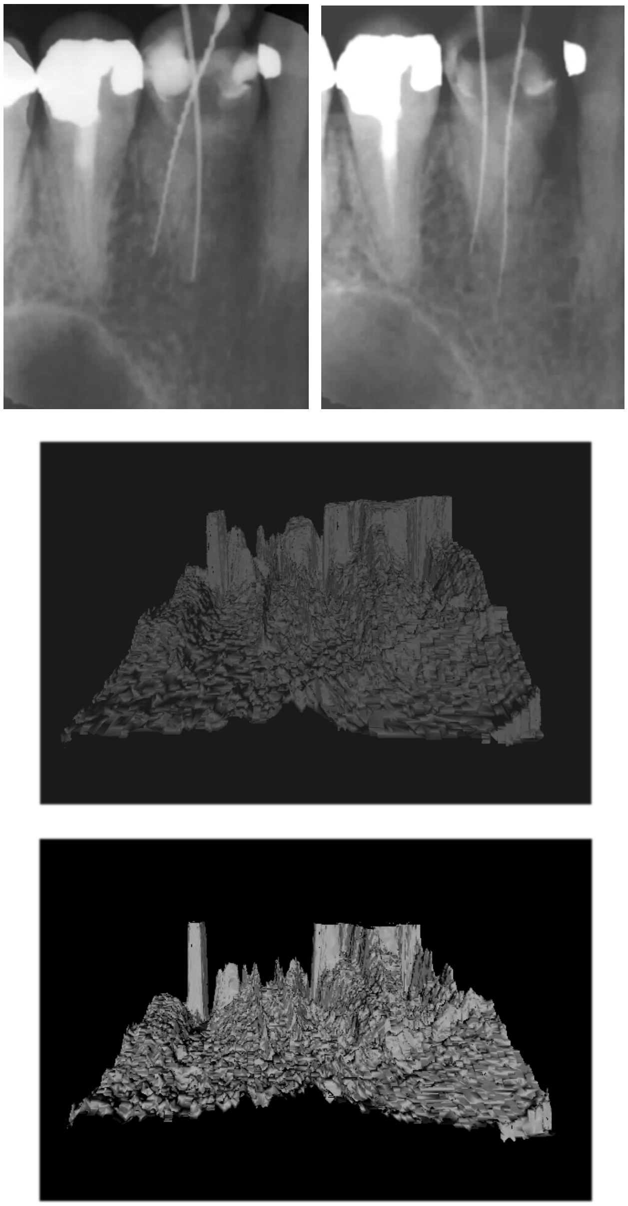
otherwise

$$f_l\left(\langle v_1, v_2, \dots, v_n, m \rangle\right) = 0 \, .$$

Lifting is similar to the umbra transform in gray-scale morphology.

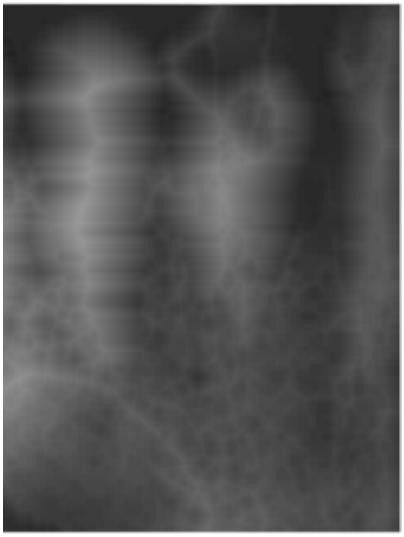
From these binary datasets, the surfaces of the lifted images are extracted and triangulated. The triangulation is performed using a standard explicit algorithm in combination with a triangle decimator based on the algorithm of [4]. The use of decimator controls the number of finally generated triangles. This number affects the time of execution and the precision of the result after the application of the scheme: The more the number of triangles, the better the accuracy of the registration result, but the time of execution increases. After a number of experimental executions of the scheme it has been finally proved that a 20% reduction of the total number of triangles affects the error in the final performance of the scheme less than 0.1% reducing in the same time linearly the time of scheme execution by 80%.

A three-dimensional distance map from the reference image is calculated whereas from the floating image, a “hut” of points belonging to the surface is extracted. The distance map is a discrete space whose each voxel holds a value equal to its Euclidean distance from the closest node of the reference image surface [5]. The distance map accelerates the process of matching two surfaces consisting of N nodes each, since it reduces the problem’s complexity from $O(N^2)$ to $O(N)$. The traditional Euclidean distance map calculation that uses floating point arithmetic was firstly included in the proposed scheme.



Floating and Reference X-Ray Images and Their Equivalent Lifting-Produced Surfaces After Decimation

The calculation of Euclidean Distance Map has a complexity of two scans of the image, one forward and one inverse. To improve the performance of the scheme the algorithm was replaced with a novel implementation based only on integer arithmetic. The later uses a circular list in order to avoid the double scanning of the image and the need of storage of temporary intermediate floating values. The list is updated in a recursive way so that each image pixel is finally assigned with the closest surface point index to it (source point). The final calculation of Euclidean distance is straight by calculating the distance of each point from each source point.



Distance Map Image Produced From the Surface of the Reference Image

Then, an affine transformation which minimizes the average distances of the surface of the reference image and the “hut” of points of the floating, over the distance map, is obtained. Affine transformation maps straight lines into straight lines, whereas it preserves parallelism between lines [1]. In the three-dimensional case, it can be mathematically expressed as follows:

$$\begin{pmatrix}x'\\y'\\z'\end{pmatrix}=\begin{pmatrix}a_1&a_2&a_3\\b_1&b_2&b\\c_1&c&c_3\end{pmatrix}+\begin{pmatrix}dx\\dy\\dz\end{pmatrix}$$

The affine transformation is completely defined by 9 independent parameters   for i=1,2,3 and dx, dy and dz, whereas, in the 2-D case, the affine transformation is defined by 6 independent parameters. In our case, when transforming a pseudo 3-D image generated from a two dimensional one, the dummy z-coordinate of pseudo 3-D space can introduce non-linear effects in the 2-D resulting image. It can be mathematically proven that the 3D affine transformation of the lifted image is a superset of the two dimensional affine transformation and also includes some special cases of the 2-D projective transformation which is given by the formula:

$$\begin{pmatrix}u\\v\\w\end{pmatrix}=\begin{pmatrix}a_1&a_2&a_3\\b_1&b_2&b\\c_1&c&c_3\end{pmatrix}\begin{pmatrix}x\\y\\1\end{pmatrix},\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{pmatrix}u/w\\v/w\end{pmatrix}$$

where w represents the extra homogeneous coordinate and u and v are dummy variables.

The optimal value of the transformation parameters is obtained using genetic algorithms (GA) as an optimization method. It has been proven in [2] the use of global optimization techniques has better performance and accuracy in difficult multidimensional registration problems.

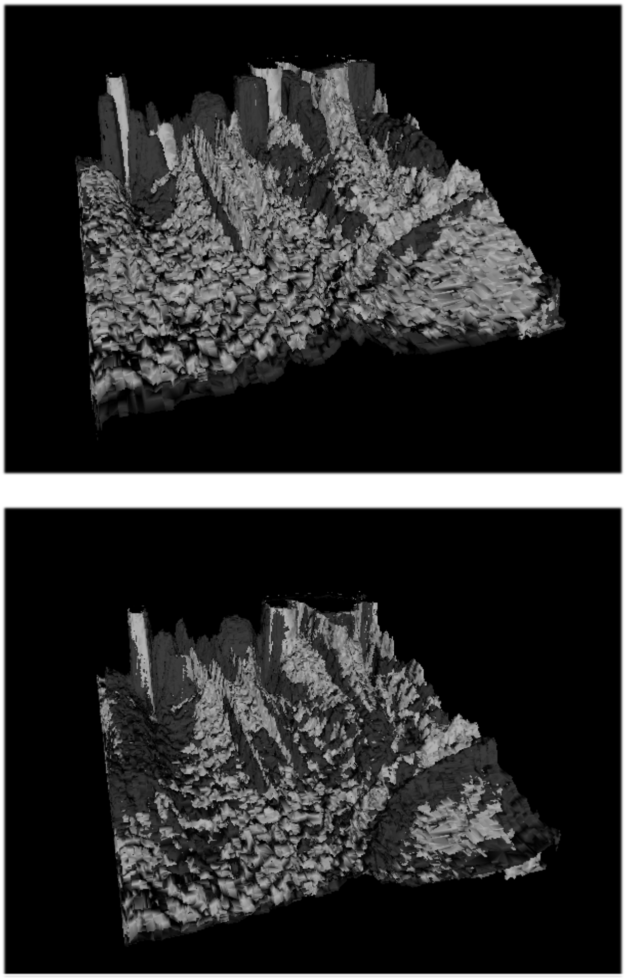
Genetic Algorithms (GAs) are global optimization methods, which were inspired by Darwinian evolution. The method starts by creating a population of random solutions of the optimization problem. A solution to the problem usually consists of the values of the independent parameters of the function to be optimized -this function is called objective function. These values often are converted to binary and concatenated to a single string, called chromosome or individual, although real encoding is also used. The method treats each individual as an organism to which it assigns a measure of fitness, or ability to survive. Each individual’s fitness is estimated by the value of the objective function calculated over the values of the parameters that are stored in the individual. Using the axiom of the survival of the fittest, pairs of fit individuals are selected to recombine their encoded parameters to produce offspring. The most basic genetic operators that act on the individuals are crossover and mutation, although a number of others have been proposed [6]. In this way a new generation of solutions is produced, that replaces the previous one. The selection pressure will direct the evolution of the population towards fitter states, which is equivalent to optimizing the objective function. This process is formulated in pseudocode as follows:

```
initialize the first generation of n individuals randomly
   while (termination_condition is false)
 {
      calculate the objective function of the n individuals
      select N/2 pairs of individuals
      apply crossover and mutation operator to produce
      offspring
      replace the current generation by the n offspring
 }
```

The convergence theorem for GAs can be expressed as following: Researchers introduced the concept of schema to mathematically formalize GAs. In the case of binary encoding of the unknown parameters, a schema is a binary string with some of the 0s and 1s replaced by wild characters (*). A schema is thought as a hyper plane of the problem’s parameter space. A schema is contained into a chromosome, if it can be produced by replacing 0s and 1s of the chromosome by *s. When decoding and evaluating a chromosome, a large number of schemata are sampled at the same time - a phenomenon that is called implicit parallelism. GAs achieve function optimization since the selection operator statistically ensures that building blocks (low order schemata with small number of non *s), which appear in fit chromosomes, propagate through generations. If the fitness f of a given schema H, is greater than the average fitness   of the current population, then the number of chromosomes containing this schema in the next generation   is expected to be greater than the number of chromosomes containing the schema in the current generation:

$$m(H,t+1) \geq m(H,t)\frac{f(H)}{\bar{f}}\left(1-p_c\frac{\delta(H)}{L-1}-o(H)p_{mut}-........\right)$$

where δ(H) and L(H) and o(H) are schema related quantities and are the probabilities for crossover and mutation. Towards the end of the search, when the population is enriched with building blocks, the crossover operator combines them to produce solutions of the optimization problem.



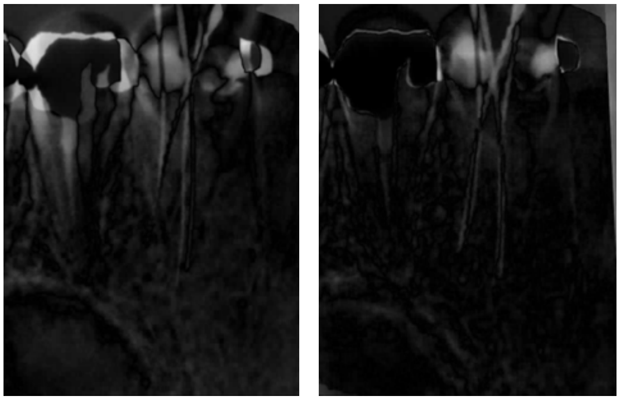
Superposition of Surfaces of the Floating and the Reference Image Before and After the Registration Procedure

The three-dimensional floating surface is finally transformed back into a two-dimensional gray scale image using the inverse process of collapsing in registered image. This operation is the complement of lifting. It converts the three-dimensional binary scene (V_B, f_B) to a two dimensional gray scene (V, f) as follows:

$$V = \left\{\left\langle v_1, v_2, ..., v_n \right\rangle \mid \left\langle v_1, v_2, ..., v_n, m \right\rangle \in V_B\right\}$$

and for all $\left\langle v_1, v_2, ..., v_n \right\rangle \in V$

$$f\left(\left\langle v_1, v_2, ..., v_n \right\rangle\right) = \max\left\{m \mid f_B\left(\left\langle v_1, v_2, ..., v_n, m \right\rangle\right) = 1\right\}$$



Absolute Error Images Before and After the Registration Procedure

3. Quantitative Results

The new algorithm has been applied on selected pairs of digital dental radiographs. By registering those dental images, the specialist can then perform any quantitative comparisons, concerning the evolution of abnormalities (cysts, tooth decay etc.) or healing processes, as well as the assessment of the effectiveness of the therapeutic scheme. Ten dental radiographic images have been acquired and digitized using a CCD camera. Then, the proposed method has been applied to the data.

Also, the proposed registration scheme has been evaluated against classical methods based on correlation coefficient and the marker based registration method. The qualitative and quantitative analysis show that the proposed method outperforms the classical method, in terms of marker distance which has been used as a golden standard evaluation criterion.

The performance of the automatic method must be tested against the most accurate similarity criterion. For this purpose, the following three criteria have been tested: the normalized cross-correlation coefficient, the gradient correlation and the mutual information. An independent measure of match is employed in order to evaluate these similarity criteria, such as the average distance, between the selected pairs of markers:

$$D_{ave} = \frac{1}{n}\sum_{i=1}^{n}\left\| T(x_{i1}, y_{i1}) - (x_{i2}, y_{i2}) \right\|$$

where $(x_{i1}, y_{i1}), (x_{i2}, y_{i2})$ $(i = 1,2,...n)$ represent the pairs of the user-defined markers, $T(x, y)$ stands for the selected geometric transformation and $\|\bullet\|$ denotes the Euclidean distance; the smaller the distance, the better the registration achieved. It was proved that the mutual information was describing in a better way the performance measure and consequently has been chosen as a quantitative measure for the evaluation of our algorithm.

A quantitative analysis was then performed in order to compare the two registration methods: the proposed automatic against the manual. These results are shown in Table I. It must be pointed out that the comparison of the two methods has been achieved using an independent measure of match, so as our results to be unbiased.

TABLE I

Comparison of the Automatic Registration Method Against the Manual One, in Terms of Mutual Information Criterion

Pairs	AUTOMATIC Registration	MANUAL Registration
1	2.896926	2.723505
2	2.291569	1.331395
3	2.375806	1.387335
4	3.087190	2.505113
5	3.044141	2.316527
6	2.100884	1.968396
7	1.684265	1.250672
8	1.814806	1.486984
9	2.710334	1.751603
Mean Value	2.445102	1.857948

It is evident that the automatic registration, using the cross-correlation, as a similarity criterion, consistently and substantially outperformed the manual registration for all pairs.

4. Conclusions

A novel automatic registration scheme has been presented and applied on X-ray dental images. The scheme introduces a new concept of registering two-dimensional data, by transforming the problem from two-dimensional gray scale mapping into three-dimensional surface matching. The results have shown the advantageous performance of the registration method with improved optimization convergence and reduced dependence on initial registration settings against classical correlation methods. Further evaluation of the proposed registration scheme is necessary in order to be incorporated, as a routine examination, on a clinical setting involving two-dimensional data from different medical imaging devices.

5. References

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