A High-Performance Image Registration Technique And Application To Multispectral Imaging For Medical Diagnosis

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Abstract. In many applications the image registration task is a fundamental prerequisite for any further processing and analysis. In the proposed paper a new efficient technique is presented, appropriate for registering images, which are translated and rotated versions of a reference image. The technique consists of two main parts: an efficiently implemented pre-whitening part and an iterative part, which yields the unknown displacements after a few iterations. The most costly part of the algorithm (i.e. cross-correlation computations) is performed efficiently via a new scheme based on a proper partitioning of the images and the use of the FFT. The new registration technique exhibits a superior performance compared to the conventional cross-correlation method. The new technique has been successfully applied in a visual diagnostic method for detecting, in vivo, epithelial dysplasias and malignancies.

1 Introduction

Over the last two decades many image registration techniques have been developed [1], [2]. Phase correlation and spatial cross-correlation are two well known techniques for image registration. In this paper we concentrate on spatial cross-correlation, which is preferable in the case that the images are corrupted by white noise [1].

The proposed technique restores both translational and rotational differences between two images. The technique comprises two main parts. In the first part, an appropriate pre-filtering is applied increasing the discrimination capability of the whole technique. Specifically, a two-dimensional prediction error filter corresponding to the reference image is computed and then applied to both the reference and the displaced image. The second part is a cross-correlation based iterative procedure that, having as inputs the pre-whitened images, yields after a few iterations the displacement parameters. The implementation of the most costly steps of the iterative part (i.e. cross-correlations) is done efficiently resulting in a considerable reduction of the overall computational cost of the technique. It should be noted that the fast scheme developed for the cross-correlations' computation is applicable to other spatial cross-correlation methods as well. The proposed registration technique has been compared with a properly modified version of the conventional cross-correlation method. Specifically, the conventional cross-correlation method has been extended according to the proposed iterative scheme, so as to tackle both translation and rotation problems. This method is called hereafter Iterative Cross-Correlation (ICC), while the method with the pre-filtering part is called Iterative Cross-Correlation with Pre-Whitening (ICC-PW). As shown via extensive simulations (and justified theoretically) the performance of the ICC-PW is superior to the ICC method and in most cases the improvement is considerable.

The new technique has been successfully applied to in vivo detection of epithelial dysplasias and malignancies. The images are acquired using a multispectral camera (that has the capability to capture images at different spectral bands) and the aim is to quantitatively assess the temporal alterations in the intensity of the back-scattered light in specific locations of the examined area. To this end, the successive images have to be aligned before any further processing. This latter task is achieved using the proposed registration technique.

The basic steps of the proposed ICC-PW and the implementation issues are discussed in

section 2, while in section 3 the medical application is described and simulation results are provided. Finally, the work is concluded in section 4.

2 The proposed technique

Let *A* be the reference image and *B* a translated and rotated version of *A*. The aim is to correct translation and rotation displacements between *A* and *B*. To this end the following procedure is suggested. First, in order to sharpen the cross-correlation peak, which may be rather broad, we suggest whitening the input images with a two-dimensional causal QP (Quarter Plane) prediction error filter h_A corresponding to a properly selected area of the reference image. Thus, an amount of redundant information is taken away from *A* and *B* and the resulting images are less correlated. In this manner, an enhancement of the discrimination capability of the cross-correlation method can be achieved. Subsequently, the new images are used as input to an iterative scheme. At each iteration step a new pair of translation and rotation displacements is computed. A similar iterative procedure based on the so-called AMDF (Average Magnitude Difference Function) method was used in [3].

Summary of the technique

1. Compute the prediction error filter, h_A, for image *A*.
2. E_A=convolution(h_A, *A*), E_B=convolution(h_B, *B*). Set *i*=1, $E_{A_0} = E_A$, $E_{B_0} = E_B$
3. Iterative step
   3.1 Translation
   - Cross-correlate($E_{A_{i-1}}$, $E_{B_{i-1}}$) and find the best match (x_i, y_i).
   - Translate $E_{A_{i-1}}$ in terms of $E_{B_{i-1}}$ according to (x_i, y_i) and extract the overlapping subimages $\tilde{\tilde{E}}_{A_i}$, $\tilde{\tilde{E}}_{B_i}$.

   3.2 Rotation
   - Rotate $\tilde{\tilde{E}}_{A_i}$ by $-\theta,-\theta+\Delta\theta,...,\theta$. Cross-correlate $\tilde{\tilde{E}}_{A_i}$, $\tilde{\tilde{E}}_{B_i}$ and find the best match ϑ_i.
   - Rotate $\tilde{\tilde{E}}_{A_i}$ in terms of $\tilde{\tilde{E}}_{B_i}$ according to ϑ_i and extract the overlapping subimages E_{A_i}, E_{B_i}.

   3.3 If $x_i, y_i, \theta_i \neq 0$, set $i = i+1$ and repeat step 3.

Note that the first two steps take place once and constitute the non-iterative part, while the third step is the iterative part of the technique. This iterative part terminates when no translational and rotational displacements from one step to another are detected. The overall translational and rotational displacements can be computed by summing the respective displacements obtained at each iteration.

Implementation issues

Efficient implementation schemes can be employed into the costly steps of the technique. Thus, the computation of the *M*×*M* 2-D prediction error filter, can be done using a Levinson-type algorithm [4], with complexity $O(M^4)$. The convolutional operations required in step 2 can be performed efficiently using FFT and the 2-D version of the overlap-save method [5]. The cost is $O(N^2 \log M)$, where *N*×*N* are the dimensions of the used sub-area of image B. Finally, a new efficient scheme has been developed for the computation of the cross-correlations involved in step 3. If *L* is the maximum translational shift, then an *N*×*N* area of image *B* and an (*N*+*L*)×(*N*+*L*) area of image *A* have to be correlated. In many cases, it can be assumed that $L<<N$ and thus it is inefficient to apply the straightforward FFT-based technique. So, an efficient scheme, based on a proper partition of the images into blocks, is proposed with complexity $O(N^2 \log L)$. Image *A* is partitioned into (*N*+*L*)/*L* overlapped and

consecutive *2L×2L* blocks and image B into *N/L* non-overlapped *L×L* blocks. Each block of *B* is flipped horizontally and vertically and zero-padded up to an area equal to *2L×2L*. The corresponding blocks of the two images are cyclically convolved, using FFT, and the resulting arrays are summed in the frequency domain to form a *2L×2L* array. Finally, we take the IFFT of this array and form the resulting one, keeping only an appropriate part.

3 Application to visual clinical diagnosis

Background Information

Recently, in [6], an imaging diagnostic method has been developed which is appropriate for the in vivo, early detection and quantitative grading of cervical and other epithelial neoplasias and malignancies. The new method relies on the quantitative assessment of the temporal alterations in the intensity of the back-scattered light (IBSL), in any spatial location of the examined area, after topical application of 3% acetic acid solution (e.g. [7]). The IBSL vs. time curves are calculated for any X, Y location of the image stack, which is collected with successive snapshot imaging, at a narrow spectral band (525±15 nm) and for about 6 min during the evolution of the tissue-whitening phenomenon. Spectral imaging and analysis of the cervix have shown that the maximum contrast between acetic acid responsive and non-responsive areas is obtained at this spectral band. Initial clinical trials have shown that the lineshapes of the above-mentioned kinetic curves contain specific and improved diagnostic information, enabling the early detection and the unbiased identification and staging of cancerous and precancerous lesions, without tissue removal.

Note that during image capturing, micro-movements of the examined tissue relatively to the camera module are always occurring, due to the patient's breathing, discomfort etc. Movements include both linear displacements and rotations. Thus, one critical factor that affects the accuracy of the method in measuring the kinetic characteristics of the phenomenon is the registration of the captured and stored temporally successive images.

Simulation Results

The performance of ICC-PW was tested on a set of cervical images, of size 558×734, (Figure 1). For each one, we considered a pair of scenes of size 200×200, with the second scene being a translated and rotated version of the first. 20 different experiments were conducted and the ICC-PW was compared with ICC.

In order to evaluate the performance of our method and to fairly compare it with the modified version of the conventional method, we used two criteria, the number of completely successful registrations (hits) and the total matching error defined as

$$D = \frac{1}{N_1 \cdot N_2} \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \left| S_A(i, j) - S_B(i, j) \right| \qquad (1)$$

where S_A and S_B are the subimages resulting after the registration of images *A* and *B* and $N_1 \times N_2$ is the number of pixels in these images.

The total matching error for the 20 experiments is shown in Figure 2. The dashed curve corresponds to the matching error of ICC, while the solid curve corresponds to the matching error of ICC-PW. Also Table 1 shows that our method has more hits and the mean value and variance of the matching error are smaller. These simulations show that the proposed ICC-PW performs better than ICC. Note that even when ICC-PW fails to find the exact displacements, the obtained estimated values are very close to the true ones, contrary to the corresponding estimates of ICC, which in some cases may differ noticeably from the true ones. Additional experiments with different type of images have confirmed the above conclusion.

Then, ICC-PW is applied to properly selected areas of a sequence of 30 cervical images,

i.e. to those considered as most appropriate for diagnostic purposes. The aim is to register the 30 images and derive the IBSL vs. time curves for the pixels within the areas of interest. The resulting curves are shown in Figure 3 and they are very close to the expected ones [6].

4 Conclusions

A new efficient image registration technique is proposed, appropriate for images that are translated and rotated versions of a reference image. The technique consists of an efficiently implemented pre-whitening part and an iterative one that yields the unknown displacements after a few iterations. The new registration technique exhibits a superior performance compared to the conventional cross-correlation method. Moreover, a computationally efficient scheme has been developed for computing the bulky computations (i.e. cross-correlation computation). The new technique has been successfully applied in a visual diagnostic method for detecting, in vivo, epithelial dysplasias and malignancies.

Acknowledgement

This work was supported in part by the Computer Technology Institute (CTI) of Patras and in part by F.O.R.T.H./IESL.

CERVICAL IMAGES	Hits	Mean	Variance
ICC method	5	5.0478	8.3293
ICC-PW method	11	1.9631	0.5744

Table 1. Results for the cervical images

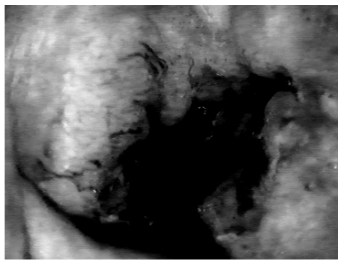

Fig 1. A Cervical Image.

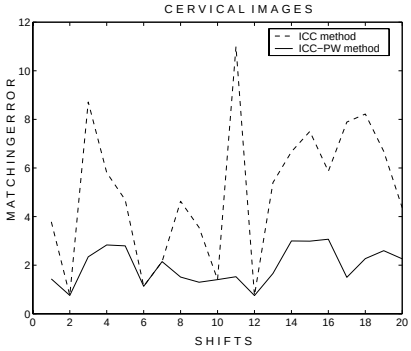

Fig 2. The Matching Error for the Cervical Images.

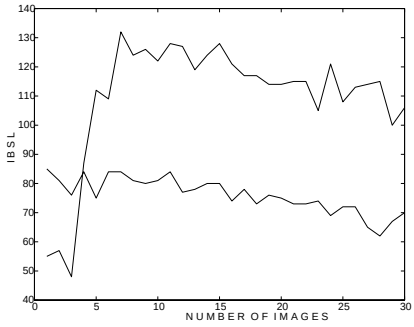

Fig 3. IBSL vs. Time curves. The quick transition of IBSL from low to high values indicates malignancies.

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