Registration of Digital Images

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Abstract - In the last few years, the Cultural Heritage field has posed its attention over image processing techniques, in particular for the diagnostic of artworks. Many different images of the same painting are taken, in different parts of the light spectrum; these different images have to be fused together, to get an augmented image showing much more details and information which are only visible in some sub-parts of the spectrum singularly. In this paper, we pose the attention over the compulsory step accomplished just before the “fusion” of such images, i.e. the registration step; in particular, we present an automatic registration technique, based on the computation of mutual information. By means of the registration, it is possible to exactly align the different images, which is the preliminary step to obtain a useful and correct augmented image. These techniques can be also applied to other areas, and in particular to remote sensing images.

Keywords: Registration, mutual information, MMI criterion, Cultural Heritage, Image Processing.

1 Introduction

For many years, the technological and the artistic field have been worlds so far apart; this is particularly true for the application of signal and image processing to the analysis of artworks, which is still a quite uncommon practise, both among conservators and ICT specialists. However, in the last few years some scientific studies started to be applied to the field of Cultural Heritage. The most used techniques were the physical and chemical methods, while computer science technologies have been considered only recently. However, several research projects started (such as the EU funded ACHOIR, CRISATEL, VASARI, NARCISSE, VISEUM, ARTISTE projects), demonstrating the usefulness of image processing methods as convenient assistants to the curators working in the field of Cultural Heritage; all of them proved the impact that digital image processing may have on all related major issues, such as material analysis (and therefore dating and provenance determination), discovery and interpretation of ancient technologies, artists’ environment and mutual relationships investigation, better knowledge of conservation materials and processes, and art dissemination and fruition.

As well as requirements from the medical field, also for art diagnostics it is often needed to observe and fuse together several sets of data coming from different sources, and stored in various images. The analysis of a painting could be performed for example comparing images taken at different time (e.g. historical pictures versus current pictures), or images acquired from different points of view or by means of different sensors (e.g. IR-reflectograms, X-radiographies etc.) that capture different and often complementary content. All of these images need to be integrated and “fused” together, in order to obtain a whole augmented image, showing an amount of details and information which are at disposal on each singular image coming from different sensors. Just before this step, all of these images have to be registered, in order to get the correct alignment among each other; to be more precise, registration is the determination of a geometrical transformation which aligns points in one picture with corresponding points in another picture.

Often, the registration step is performed manually by an user, iteratively setting the parameters of the geometrical transformation and checking its performance. However, this approach is time consuming and can often give subjective results. In this paper we propose the application of an automatic registration technique based on the computation of mutual information. We applied this method for the automatic registration of 14 multispectral images of the same area of a painting, 7 relative to the UV induced visible fluorescence, and 7 relative to the reflectance in the visible range. The multispectral images were acquired with a monochrome CCD camera equipped with a filter wheel, and resulted translated or scaled with respect to each other due to a different optical path and some ran-
domness in the positioning of the filter in front of the camera’s objective. The automatic registration procedure was successful even when the image content was significantly different and when we considered only a small portion of the image, which allowed a much faster processing. The results are presented at the end of the paper.

2 Image Registration

As already stated, an image registration algorithm aims at the determination of the parameters of a geometrical transformation mapping points in one picture, the reference (or target) one, with corresponding points in another picture, the sensed (or template) one [1]. There are several proposed methods and many ways of classify them. One of the most interesting classifications of these algorithms is the one based on the basis, i.e. the set of points or features that are involved in the registration task [1]. According to this, registration methods can be classified in point-based methods, surface-based methods and intensity-based methods.

The point-based methods identify a priori a certain number of points, manually selected or externally superimposed, over both the to-be-registered images; the registration process looks for the displacement between these points. The surface-based methods determine corresponding surfaces (instead of points) in the two images and try to find the transformation that best aligns these surfaces. Finally, intensity-based methods calculate the transformation using the pixel values alone, with no reference to distinctive points or surfaces, through an iterative optimization of a similarity measure. Within this class, one of the more interesting methods is the one based on the maximization of the mutual information (MMI) [2], that has shown excellent results for the registration of medical images, compared to previously proposed methods, which can often fail when dealing with multi-source images, for the inherent difference of the image structures and tone dynamics. Moreover, this method is automatic, and does not need any preprocessing.

In the field of Cultural heritage applications, image registration algorithms were already introduced in [3]; here, two different approaches were used to align an historical photograph and a current one of a mosaic. First, a point-based method was used, manually selecting 20 salient point pairs. Next, the MMI algorithm was used for the refinement of the feature locations, by applying this method to windows centered in the selected points. Here, a completely automatic algorithm is proposed.

3 MMI-based image registration

Mutual information (MI), a basic notion coming from information theory, represents a measure of the amount of information that one image contains about another one. The MMI approach states that MI between two images is maximum when the images are correctly registered. Let us suppose that two images $X$ and $Y$ are related by the geometric transformation $T_\alpha$, represented by the geometrical parameters $\alpha = [\alpha_1, \ldots, \alpha_n]$, such that the pixel $p$ of $X$ with intensity value $X(p) = x$ corresponds to the pixel $T_\alpha(p)$ of $Y$ with intensity value $Y(T_\alpha(p)) = y$. Then, the mutual information between the two images is:

$$I(X,Y) = \sum_{x,y} p_{XY}(x,y) \log_2 \frac{p_{XY}(x,y)}{p_X(x) \cdot p_Y(y)} \quad (1)$$

where $p_{XY}(x,y)$ is the joint probability distribution, $p_X(x)$ and $p_Y(y)$ the marginal ones. The mutual information registration criterion states that the two images are geometrically aligned by the transformation $T_\alpha^*$ such that:

$$\alpha^* = \arg \max_{\alpha} I(X,Y) \quad (2)$$

Estimates for the joint and marginal distributions can be obtained by simple normalization of the joint and marginal histograms of the overlapping parts of both images [4]. The joint histogram $h_\alpha(x,y)$ is obtained by binning the pixel intensity value pairs $(X(p),Y(T_\alpha(p)))$ for all the pixels in the overlapping region of $X$ and $Y$. Since very often the registered pixel position $T_\alpha(p)$ will not coincide with a grid position, an interpolation of the reference image will be required to obtain the pixel value $Y(T_\alpha(p))$. Next, the joint distribution can be estimated as:

$$p_{XY,\alpha}(x,y) = \frac{h_\alpha(x,y)}{\sum_{x,y} h_\alpha(x,y)} \quad (3)$$

and the marginal ones as $p_{X,\alpha}(x) = \sum_y p_{XY,\alpha}(x,y)$, and $p_{Y,\alpha}(y) = \sum_x p_{XY,\alpha}(x,y)$.

By using these values in Eq. (1) it is possible to derive the Mutual Information $I(X,Y)$, whose maximization will give us the optimal registration parameter $\alpha^*$.

3.1 Implementation Issues

In general, the implementation of the proposed registration algorithm is strictly dependent on the geometrical transformation model considered. In our case, we know that, due to the camera optics, the transformation the images undergo is a combination of translation, rotation and scaling, that can be represented as [1]:

$$\vec{x}' = S \cdot R \cdot \vec{x} + \vec{l} \quad (4)$$

where $\vec{x}$ is the coordinate vector of a single point before transformation and $\vec{x}'$ after it, $\vec{l} = [t_x, t_y]$ is the translational displacement, $R$ is the $2 \times 2$ rotation matrix:

$$R = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \quad (5)$$

and $S$ is a diagonal matrix $S = \text{diag}(s_x, s_y)$, whose elements represent the scaling factors along the two
axes. In the condition of isotropic scaling, as we assume, $s_x = s_y = s$; thus, the previous equation (4) can be simplified as follows:

$$\tilde{x}' = s\tilde{x} + \tilde{t}$$

(6)

where $s$ is a scalar value. In our implementation, thus, the geometric parameters are $\alpha = [t_x, t_y, \theta, s]$. The maximization process is in the actual implementation an heuristic search procedure, in which the 4 scalar parameters are iteratively changed by small amounts.

Another important issue to be taken into account is the fact that, in general, the modified pixel position $T_\alpha(p)$ will not fall into a point of the pixel grid, so that an interpolation will be required to obtain the pixel intensity value $Y(T_\alpha(p))$. Several interpolation methods can be used. The first method we have implemented is the Partial Volume (PV) interpolation, proposed in [5], that increments the joint histogram corresponding to all the four nearest neighbors $n_i$ ($i = 1, \ldots, 4$) of the pixel $T_\alpha(p)$, according to the weights $w_i$, inversely proportional to the distance between $n_i$ and $T_\alpha(p)$. However, experiments showed that PV interpolation introduces some artifacts in the MMI computation. In particular, PV interpolation yields local maxima of MI at integer pixel positions (more details on this effect can be found in [5]). Thus, we implemented the bilinear (BI) interpolation algorithm [5], that exhibited a good performance. The BI method computes the intensity value of the interpolated pixel $T_\alpha(p)$ as a weighted sum of the intensity values of the four nearest neighbors $n_i$ ($i = 1, \ldots, 4$), according to weights $w_i$, so that $\sum_i w_i(T_\alpha(p)) = 1$; the joint histogram is then incremented according to this computed value, as described:

$$Y(T_\alpha(p)) = \sum_i w_i \cdot Y(n_i) \cdot h_\alpha(X(p), Y(T_\alpha(p))) = +1$$

(7)

4 EXPERIMENTAL RESULTS

In this section we present some of the experimental results obtained by applying the implemented MMI-based registration algorithm to a real case of art-works analysis. We investigated the images of a detail from an actual painting. The final goal of the investigation was to achieve a multispectral calibrated UV fluorescence image of the painting surface. In order to achieve it, data was needed from a set of monochrome images, acquired in different wavebands, both of the UV induced visible fluorescence images and of the white light radiance.

The multispectral images, acquired with a CCD camera equipped with a filter wheel, could be translated or scaled with respect to each other, due to the different optical path for each filter, a possible relative misaligned position of the corresponding filters in the filter wheel or a slightly different distance of the acquisition system from the painting in the measuring sessions. To combine correctly the different information provided by the multispectral images a registration algorithm was needed. If only considering the number of images to be used, an automatic registration was to be preferred. In order to make the processing much faster the procedure has then been applied only on a small portion of the images, and then the estimated transformation $T_\alpha^*$ is successfully adopted for the whole image.

As mentioned in the previous section, two interpolation techniques (partial volume PV and bilinear BI) have been implemented and compared. Since we are interested to a sub-pixel precision for the geometrical transformation existing between target and template image, we found that the BI algorithm provides more reliable results, given that PV interpolation yields local maxima of MI at integer pixel positions, thus favoring integer pixel transformation. Such a behavior is evident in Fig. 1(a), where the MI is represented as a function of translation $[t_x, t_y]$ for a subpart of the two images, using the PV interpolation method. In Fig. 1(b) the corresponding result by using the BI interpolation is shown, and the two maxima (the one related to PV and the other related to BI) are indicated, thus highlighting that by adopting PV the real maximum is lost.

The MMI-based registration algorithm with BI interpolation was then applied to obtain a multispectral calibrated UV fluorescence image of the painting surface. Firstly, all the UV images (with respect to a chosen UV target image) were registered; similarly, all the white light images were registered with respect to a chosen white light image. In Fig. 2 an example of the second step of this procedure is shown: small portions of two white light images to be registered are presented, respectively the target (wavelength of 400 nm) in Fig. 2(a) and the template (700 nm) Fig. 2(b). The absolute difference between the target and the template and between the target and the registered template are in Fig. 2(c) and Fig. 2(d); let us note that such a difference decreases after registration. A similar procedure has been applied for registering the reference UV image (at 400 nm) with the reference white light image (again at 400 nm). Although in this case the structure of the two images is quite different, as presented in Fig. 3(a) and 3(b), nevertheless the MMI algorithm leads to reliable results, as demonstrated by the comparison of the absolute differences between the two images before and after the registration (Figures 3(c) and 3(d)). The registered UV and white light images could be used to obtain the RGB calibrated image of the painting fluorescence emission in the visible range, where all the
Figure 2: Two small portion of two white light images to be registered, respectively target (a) and template (b). The absolute difference between the target and the template (c) and between the target and the registered template (d) (i.e. $\alpha = [t_x = -0.4, t_y = +1.2, \theta = 0, s = 1]$ and the resulting $MI = 1.33$).

Figure 3: Particular of the two images to be registered: the white light radiance target image (a) and the UV induced visible fluorescence template image (b). As it is shown, the content of the two images is significantly different. The geometrical parameters maximizing MI are $\alpha = [t_x = -0.5, t_y = -0.3, \theta = 0, s = 0.99]$ and the resulting $MI = 1.30$.

information provided separately by the single images are merged. This is a practical example of how such a registration method could be usefully adopted in the conservation field.

The above explained technique can be also successfully applied to other fields, such as medical imaging and remote sensing imaging. With particular regard to the remote sensing imaging, some experiments have been also performed, applying the registration method to aerospace images.

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