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Field-warp registration for biomedical high-resolution thermal infrared images

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Abstract— **Biomedical protocols based on thermal infrared images often require effective image registration. Algorithms specifically designed for registration of thermal images are hardly available and use of algorithms designed for other imaging techniques may result poorly reliable. In fact, registration algorithms developed for other biomedical images often require rigid-body assumption or limited range for intensity values. Such assumption may not be applicable for human body thermal images. Therefore, we present here an adaptation of a field-warp based method as a possible solution for thermal image registration. The method was applied for registering images taken from an experimental protocol aimed at comparing total body skin temperature distribution in natural or altered posture.**

The method appears to be effective into providing a reliable tool for objective intra and inter individual skin temperature distribution comparisons.

I. Introduction

Image registration process is defined as the spatial and temporal alignment of a set of images to a given spatial and temporal reference [16]. A common requirement for medical imaging is to register two-dimensional (2D), three-dimensional (3D), and even four-dimensional (3D + time) images. Registration is needed when images are relative to the same anatomical location, but recorded using different imaging modalities (cross-modality registration), or at different times (cross-temporal registration), or in case of only partially overlapping images (spatial registration). In all of these cases, the goal is to produce a fused image or an image sequence, from which to extract meaningful clinical information [9]. This paper proposes a method for the registration of sets of thermal infrared (IR) images for biomedical applications.

In spite of the validity of its physiological fundament for diagnostic use, medical thermography did not achieve results considered sufficiently reliable in terms of clinical specificity and diagnostic accuracy [6, 10]. Among the acknowledged reasons for such outcome, a major role was played by the poor technology (low thermal sensitivity and sampling frequency) and the reduced processing capability due to unavailability of digital data [6].

Nevertheless, although not for biomedical purposes, an extraordinary technological development has concerned the IR imaging devices along the '90s. Consequently, a renewed interest has regarded the biomedical application of IR imaging. Many new procedures – based on analysis and modelling of the time evolution of the skin temperature distribution - have been proposed [10, 6,10,12,14]. For many of them, cross-temporal or across-subjects registration is a mandatory requirement [2, 12]. Registration algorithms dedicated to IR images are not available and the use of algorithms developed for other imaging techniques (such as Magnetic Resonance Imaging) is not always suitable or not providing adequate image registration when applied to thermal images. In fact, many of them rely on detection and tracking of specific anatomical features [8], while thermal images are not anatomic-morphological images, but functional images reporting pixel by pixel the skin temperature. For a given subject, the temperature distribution may widely change over time, therefore preventing the use of algorithms based on searching for local minima or specific intensity values. Moreover, geometry of skin temperature distribution may largely differ from individual to individual, thus not permitting to anchor the individual geometries to common landmark features [8].

In this paper, we present and test a field-warp based registration method that we have specifically developed for thermal IR images.

II. Field-warp registration methodology

Several methods for image registration are available [9]. They are usually classified on the basis of the registration criteria [4]. A detailed description of all of the methods is beyond the aim of this paper. Therefore we address the interested reader to [16] for a general review. IR images are usually two-dimensional. Therefore, a monomodal 2d-2d registration, using a local curved transformation, is required [7]. Field warp methods may provide a feasible solution to satisfy such requirement [1, 16]. The method presented in this paper bases its core structure on the original idea published in 1992 by Beier and Neely [1]. In their method, a warp technique is used to transform the **source** image (i.e., the one that has to be registered) into the **destination** image (i.e., template) by morphing.

The parameters for the warping are obtained through the following steps:

i) Define one or more mapping oriented segments on the destination image;

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ii) Identify the corresponding mapping segments on the source image;

iii) Re-map the source image computing the actual position of each pixel with respect to the source image mapping segments;

iv) Create a new warped image using the mapping segments defined in i) and the actual coordinates obtained in iii).

Figure 1 shows an example of coordinate mapping as above mentioned. The position with respect to the mapping segment PQ of a generic pixel X in the destination image is expressed by the coordinates couple *(u,v)*.

The *u* coordinate is defined as the distance between the segment origin P and the intersection of the segment perpendicular to PQ and passing through X. The *v* coordinate is the distance of X from PQ, measured along the same perpendicular segment. The coordinates of the corresponding point X' (*u', v'*) in the source image are similarly defined with respect to the source image mapping segment P'Q'.

Therefore, (*u,v*) are given by:

$$u = \frac{(X-P)\cdot(Q-P)}{\|Q-P\|^2} \qquad (1)$$

and

$$v = \frac{(X-P)\cdot perpendicular(Q-P)}{\|Q-P\|} \qquad (2)$$

where:

$X = (i,j)$ represents the actual pixel coordinate in the destination image;

$P = (i_P,j_P)$ represents the actual pixel coordinate of the origin of the oriented mapping segment in the destination image;

$Q = (i_Q,j_Q)$ represents the actual pixel coordinate of the end of the oriented mapping segment in the destination image;

perpendicular(Q-P) is a vector orthogonal to (*Q-P)* and having *(Q-P)* same length;

||*Q-P*|| measures the distance between *P* and *Q*.

The actual position of X' in the source image (corresponding to the X position in the destination image) is then given by:

$$X' = P' + u\cdot(Q'-P') + \frac{v\cdot perpendicular(Q'-P')}{\|Q'-P'\|} \qquad (3)$$

where:

$X' = (i',j')$ represents the actual pixel coordinate in the source image;

$P' = (i'_P,j'_P)$ represents the actual pixel coordinate of the origin of the oriented mapping segment in the source image; $Q' = (i'_Q,j'_Q)$ represents the actual pixel coordinate of the end of the oriented mapping segment in the source image;

perpendicular(Q'-P') is a vector orthogonal to (*Q'-P')* and having *(Q'-P')* same length;

||*Q'-P'*|| measures the distance between *P*' and *Q'*.

Figure 2 shows an example of coordinate mapping and resulting warping for a given bi-dimensional figure with respect to a single or multiple segment(s) mapping. Since for more effective warp transformation, multiple segments pairs are usually given [1], the displacement of a given point in the source image can be actually computed by a weighted sum of the mapping related to each individual mapping segment [1]. With respect to each mapping segment, the weights for each point X are then estimated according to the following formula:

$$weight = \left(\frac{\|Q_{i\text{-th}} - P_{i\text{-th}}\|^{p}}{a + dist}\right)^{b} \qquad (4)$$

Where *dist* is the distance of X from the nearest point of each *i-th* mapping segment; *a*, *b* and *p* are constant terms taken from [1] to take into account the relative positions and length of the mapping segments.

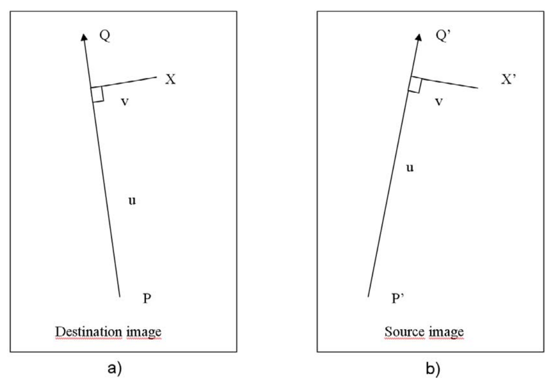

Fig. 1. Example of coordinate mapping. On the left, the destination image where X is a generic point and PQ is the mapping segment; on the right, the source image where X' is the corresponding-to-X point and P'Q' is the mapping segment in the source image. The actual coordinates of X and X' are mapped and expressed in function of PQ and P'Q', respectively.

The final new coordinates for the point in the source image are then given by:

$$X' = X + \frac{\sum_i D_i * weight(X,i)}{\sum_i weight(X,i)} \qquad (5)$$

Where the sum is taken with *i* ranging from 1 to the number of the mapping segments; D_i is the computed displacement of $X'_{i\text{-th}}$ with respect to X; *weight (X, i)* is the weight for X with respect to the *i-th* mapping segment. Figure 3 shows an example of warping based on multiple mapping segments. Figure 2b reports the effect of warping using multiple mapping segments on an extended and complex object.

III. EXPERIMENTAL PROCEDURE

To test the reliability and the effectiveness of the field-warp registration methodology on real biomedical IR image series, we used data from the following experimental protocol.

A. Experimental Protocol.

IR images were recorded to verify whether a controlled change of the natural posture may effect the skin temperature distribution in healthy volunteers. In this case, image warping is required for objective assessment of variations in skin temperature distribution because postural changes may modify apparent size and shapes of the body [11], and the skin temperature itself. The change of posture was obtained asking to the subject to wear special shoes, one of which having a 2–centimetre heel higher than the other one. Two total body image series were acquired from the same subject: the first series with the subject having bare feet (TB_0) and the second one while the subject was wearing the special shoes (TB_H). Ten subjects were studied so far. Ethical Committee of the School of Medicine, Chieti-Pescara University, approved both original studies and use of data for the present study.

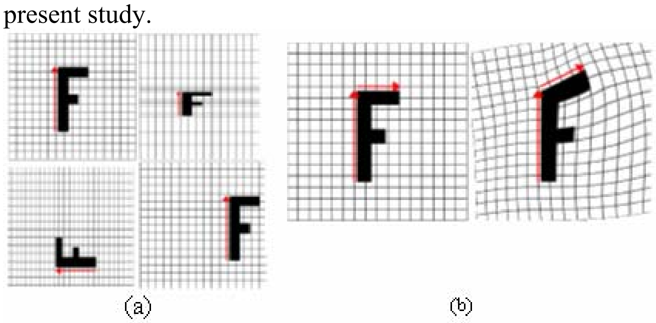

Fig. 2. Warping objects. a) Coordinate mapping with respect to a single segment allows for warping objects in the image according to the deformation in size and orientation. The figure on the upper left is the original image. The segment is scaled in the upper right image, rotated in the lower left image, and translated in the lower right image, performing the corresponding transformations to the image. b) Coordinate mapping with respect to a pair of segments allows for more complex warping (adapted from Beier and Neely (1992))

B. Materials and Methods.

IR images were acquired by means of a 14-bit digital thermal camera AEG 256 PtSi (AEG Aim Heilbronn, Germany; 256x256 PtSi Focal Plane Array; 3-5 μm spectral range; 0.1 K Noise Equivalent Temperature Differences (NETD); 31 Hz sampling rate; optics: germanium lens, f 50, f/1.5). Thermal response of the sensors matrix was blackbody-calibrated. Camera was set 3.5-4 meters far away from the subject, such a setting allowing for imaging the desired projection of the whole subject's body at once.

The subjects observed standard preparation rule to the biomedical thermal imagery [10]. Paper markers (Fig. 4) were put on few anatomical landmarks (reference points) to provide objective features to define the extremities of mapping segment through the image series.

C. Image Processing.

Thermal IR image series were processed off-line and correct from shift/drift artefacts. Then the operator selected a set of mapping segments in each image using both markers and edges of the body as reference (Fig. 4). For each series, the first image was assumed as destination image (Fig. 4). The remaining images of the series were used as source images and consequently warped (Fig. 4). On the series of warped image, digital subtractions were performed through images correspondent to the same region of interest to evaluate the temperature differences and obtain objective image comparison (figure 5). Image processing was performed through Matlab (The Mathworks, Inc.).

IV. RESULTS

Wearing shoes having different heels determined an irregular shape deformation of the subject' body contours that could not be corrected through simple affine transformation or similarity transformation. As an example, we report images from posterior view of one on the studied subject (Figure 4). Applying the proposed field-warp method, the corresponding mapping segments overlapped each to the other, as it can be appreciated by image subtraction between warped and destination images (Figure 5).

Interestingly, such an image difference allowed the identification of the local skin temperature variations possibly associated to the postural changes (Figure 5c).

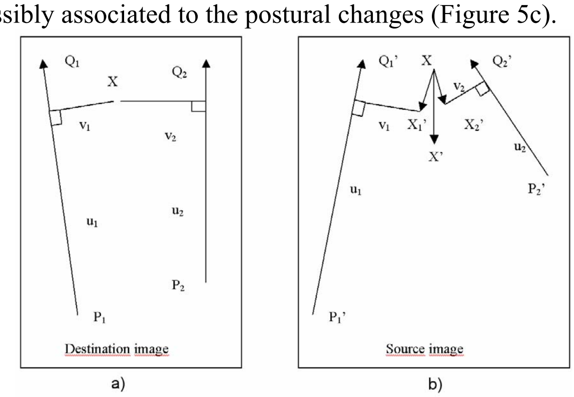

Fig. 3. Mapping based on two segments. In this case, coordinate mapping is based on the weighted sum of the displacements computed with respect to each of the two mapping segments. The final position of X', that is the position of X in the source image, is obtained by a weighted average of the estimated position of X with respect to each mapping segment (X1' and X2', respectively). The contribute of each mapping segment is weighted on the basis of its length and its distance from the point to be mapped.

V. DISCUSSION AND CONCLUSIONS

A field-warp method for image registration of biomedical IR images has been presented. The method is based on a previous algorithm by Beier and Neely (1992) and it relies on the computation of actual coordinates of the pixels in a given region of interest with respect to user-defined mapping segments.

The coordinates are then re-mapped according a weighted average of the change in position of the mapping segments between the source image and the destination image. The choice of the mapping segments relies on the availability of landmarks provided by skin paper markers and/or anatomical reference points clearly identifiable in the thermal images. The propose technique provides effective local transformation of images and can be applied to correct distortions with high number of freedom degrees, although requiring just a limited number of mapping segments. The proposed technique is semi-automatic because it requires to the operator: i) to initialize the algorithm defining the mapping segments on the destination image; ii) to identify the corresponding mapping segments on the source images, in the proper order (i.e., features detection and matching). Although with these limits, the field-warp technique allows an effective tool for objective intra-individual and inter-individual thermal image comparison. Such a comparison is, in fact, one of the most challenging aspects of biomedical thermal imaging. Further research is needed to improve the method and to make it completely independent from operator's input.

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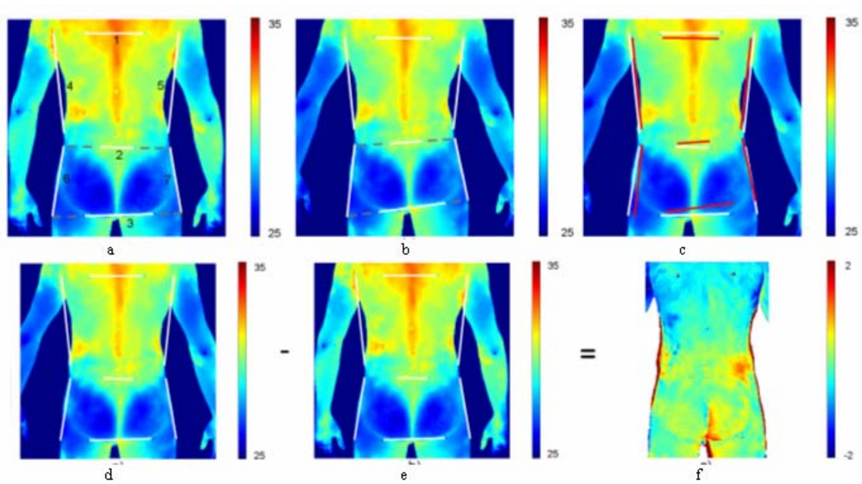

Fig. 4. Warping of the posterior view for one of the studied subjects. a) Destination image with the user-defined mapping segments; Dot lines represent the prolonged segments. b) Source image to be warped with actual position of the corresponding mapping segments; c) warped image. Red segments are the mapping segments in their original positions on the source image; white segments represent their actual position on the warped image; d) Destination image b) warped source image with the actual position of the mapping segments; c) difference image between destination and warped images. The image subtraction between registered images allowed a clear identification of the variations in the skin temperature distribution induced by the postural change. Among those, we point out the one over the right lumbar region, corresponding to the limb with the higher heel shoe.
Temperatures on colorbar are expressed in °C.