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Warping-based co-registration of thermal infrared images: Study of factors influencing its applicability

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HIGHLIGHTS

- A feasibility study on warping procedure on infrared thermal images is proposed.
- Warping accuracy strongly depends on the acquisition distance of the thermal images.
- Warping accuracy is influenced by the target inclination angle.
- Warping accuracy is not influenced by the users' expertise in thermal imaging.
- Warping accuracy is higher for local than global warping transformations.

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ABSTRACT

A relevant issue for processing biomedical thermal imaging data is the availability of tools for objective and quantitative comparison of images across different conditions or subjects. To this goal, a solution can be offered by projecting the thermal distribution data onto a fictitious template to obtain a common reference for comparison across cases or subjects.

In this preliminary study, we tested the feasibility of applying a warping procedure on infrared thermal images. Fifteen thermal images of checkerboard were recorded at three different distances and five different angles in order to evaluate which factor mostly influences the warping accuracy.

The accuracy of three different warping transformation models (local weighted mean (LWM), polynomial, affine) was tested by comparing the positioning error between users' selected fiduciary points on each thermal image and their corresponding reference position assigned on the template image.

Fifteen users, divided into three groups upon on their experience in thermal imaging processing, participated in this study in order to evaluate the effect of experience in applying a warping procedure to the analysis of thermal infrared images.

The most relevant factor influencing the positioning and thermal errors is the acquisition distance, while the users' level of experience and the inclination angle do not seem to play the same importance. Comparing the three transformations, the LWM seems to be the best in terms of minimizing the two categories of errors. This preliminary work helps to understand the limits and the possibilities of applying warping techniques for objective, quantitative and automatic thermal image comparisons.

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1. Introduction

Thermal InfraRed (IR) imaging or thermography is a widespread imaging technique used to accurately evaluate the thermal distribution of a body without any contact between the sensors and the body itself. Thermal imaging devices, or thermal cameras, are able to capture the body infrared radiation and convert it into a thermal image. Modern thermal IR cameras allow counting on both very high spatial (up to 1280×1024 pixel), temporal recording resolution (full frame frequency rate up to 200 Hz) and high thermal sensitivity (up to 15 m K @ 30 °C) in the spectral range [3–5 and 7–14] μm [1]. Thermal IR imaging is used in various fields of applications, from the mechanical to the electrical, as from the industrial to the buildings to the biomedical fields [18].

A very relevant issue for advanced processing of thermal imaging is the availability of tools for objective and quantitative comparisons of thermal images and data among conditions or samples. This need is particularly important in the biomedical field, especially with human subjects. To this goal, a co-

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registration approach should be followed, either to co-register the thermal images among them for further processing or comparison, and to project even a full dataset over a reference template to obtain a group temperature distribution for a given condition. Such a capability allows, in fact, to overcome the operator-dependent effects (potentially occurring for region of interest-based analysis) and opens up the way to effective group analysis, the same way they are currently performed in neuroimaging through the use of brain atlases (e.g., Talairach coordinate system of the human brain [2]).

In this paper, we evaluated the feasibility of pursuing the co-registration of thermal images by applying an image warping approach.

Image warping is an imaging processing technique based on the determination of a spatial transformation which maps all the pixels of one image onto the pixels of another image. It is a very useful tool in the image processing field as it allows the co-registration of two or more images [4–6], to align an image with a reference grid such as a map or a template [5], or to remove optical distortions introduced by the acquisition device [7,8].

Image warping might be provided by the detection and matching of some relevant features such as corresponding sets of points between images, local measurement of correlation between images or edges overlapping [5,9,10]. The following operations consist in (i) the estimation of the transformation model (mapping function), (ii) image resampling and (iii) image transformation [10].

The transformation model is chosen depending on the specific application and on the particular set of images to warp. The mapping function could be either global or local: The former uses all the control points (CPs) for the estimation of a set of parameters valid for the whole image, and the latter considers the image as a composition of patches (typically triangles), determining a function parameter for each patch.

There are several works concerning the registration between visible and thermal images. In 1989, Toet et al. introduced a hierarchical image merging scheme based on a multi-resolution contrast decomposition (the ratio of a low-pass pyramid) [12].

Over the next years, affine transformation methods have been proposed to register the thermal image on its corresponding visible one. For instance, in 2006, Schaefer et al. used an affine transformation to register thermal frames and visible images to obtain a fusion image [11]. In 2007, Istenic et al. employed a multi-sensor registration in the Hough-parameter space for building images [13], while Kong et al. utilized multiscale fusion of thermal and visible images to obtain a reliable face recognition, independent from illumination conditions. The combination of both imaging techniques improved the recognition performances under a wide range of illumination change [15]. In 2009, Howell et al. made use of an affine transformation for the visible-infrared registration to assess the skin temperature and blood flow in childhood localized scleroderma [14]. In 2013, Cheng et al. elaborated a motion tracking system through a template-based algorithm. They estimated the motion parameter of the template image using an affine warping model; Lucas-Kanade algorithm was then applied to search for the optimized parameters of the warping function [17]. More recently, in 2014, in order to monitor mental stress in a contactless way, Mohd et al. developed a new approach in the registration of facial thermal-visible by using a nostril mask and by adopting the Scale Invariant Feature Transform (SIFT) for point extraction and matching. The percentage of correct registration matching was 86% [16].

Finally, first attempts for obtaining a group atlas of temperature distribution for the whole human body were also performed by Ring and colleagues [3]. They developed a procedure based on the identification and selection of 87 regions of interest on 27 specific views of the body, following the Glamorgan protocol. They created a first database of thermal distribution on subjects between 18 and 70 years old.

In this work, we aimed at demonstrating the feasibility of registering one or more thermal images onto a common template image. To this goal, we warped a sample of thermal images of a chessboard acquired at different distances and inclination angles on a reference template (reference chessboard). The recorded images were not corrected for thermal reflections and uniformity to replicate standard real-life experimental conditions.

To establish the feasibility of the warping process, we compared a set of points, manually positioned by operators (OP points), with a reference standard point distribution (REF points), obtained from the thermal chessboard with a semi-automated procedure. We then determined the positioning and thermal errors between the blobs derived from OP and REF points.

We estimated the same categories of errors (positioning and thermal errors) between OP points and the back-projection of the reference template points (Back Projection point, BP), obtained from each of the three transformations, to compare the performances of the three different mapping warping functions (affine and polynomial, i.e. global transformations, and local weighted mean (LWM), i.e. local transformation). The paper is structured as follows: In the Material and Methods section, we describe the experimental technique and procedure, focusing on the definition of a reference standard, used to estimate the positioning and thermal errors respect to the real experimental measurement obtained by users. Positioning and thermal errors are also evaluated respect to the specific warping transformation. The Results section presents the statistical analyses conducted on the above-mentioned errors, while the Discussion and Conclusion section discusses and establishes the feasibility of the present study, and suggest which mapping transform performs best in terms of positioning and thermal errors.

2. Materials and methods

2.1. Procedure

A home-made thermal chessboard was used for the purpose of this study. It was built on a plexiglass plane surface, surrounded by a cardboard, and it was composed of 108 blobs (~20 mm^2 each; vertical side dV = 20 mm, horizontal side dH = 19 mm), realized by the alternation of two different materials with different emissivity: aluminum sheet on double-sided tape blobs and white painted plexiglass blobs (Fig. 1(a)). The alternation of the two different materials allowed the clear distinction between blobs in the thermal images (Fig. 1(b)). In order to always place the chessboard with the same orientation during the acquisition, a distinction element was included in the right bottom corner of the chessboard, consisting in 3 not-alternating blobs. The checkerboard was composed of 9 rows and 12 columns.

A series of thermal images of the chessboard were acquired using a thermal camera FLIR SC655 (640×480 bolometer FPA, NETD < 50 m K @ 30 °C). More precisely, 5 thermal images of the chessboard were acquired, one for each of the 5 inclination angles (Fig. 2) at 3 different distances of acquisition (150 cm, 200 cm, 250 cm). The acquisition angles were $-60°$, $-30°$, 0°, 30° and 60° with respect to the vertical axis, corresponding to 0° (Fig. 2).

Therefore, the complete set of thermal images to warp was composed of 15 images (5 inclination angles (Fig. 2) $\times$ 3 acquisition distances).

The images were acquired in a completely thermal controlled room, with a stable temperature of 23 °C.

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