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Evaluation of feature-based registration in dynamic infrared imaging for breast cancer diagnosis

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Abstract— **Dynamic Infrared Imaging has been proposed in literature as an interesting adjunctive technique to mammography in breast cancer diagnosis. For a correct analysis of the infrared image sequences, however, a preprocessing registration step may be fundamental. In this paper, we provide a first quantitative evaluation of the performances of registration on dynamic infrared images for this specific application. We propose an algorithm for the automatic control point localization and employ a feature-based piecewise linear registration approach. The quality of the image alignment is evaluated on a small sample of subjects, considering both alignment and localization errors. Results show that subject movement of up to five pixels is compensated, obtaining a subpixel error correction.**

Keywords— **Dynamic infrared imaging, breast cancer diagnosis, image registration, thermography, upsampling.**

I. INTRODUCTION

In oncology, perhaps even more than in other diseases, the importance of a timely and accurate diagnosis is fundamental. In breast cancer in particular, x-ray mammography has been recognized as the gold standard for screening and is generally accepted as the most reliable and economically convenient solution for an early diagnosis. However, in some segments of the population, especially in women on estrogen replacement therapy and with dense breast tissue, lower sensitivity values have been reported [1], and the lower efficacy of mammography in young women is a recognized fact. Consequently, the availability of techniques capable of making an early and accurate diagnosis in young women would be important in augmenting the possibilities for survival.

Thermography has been proposed as a possible adjunct to mammography in screening since the early '70s, yet static thermography, i.e. the simple measurement of breast skin temperature, has not yielded satisfactory results [2]. More recently, Dynamic Infrared Imaging (DIRI) has been proposed as an evolution of the method, which consists in the acquisition of several breast skin temperature images at a frame rate ranging from 50 to 200 frames/s. Through the analysis of the temperature fluctuations in time, information on local perfusion is reportedly obtained. This has an important diagnostic value in oncology as tumors are known to present significantly abnormal vasculature, as compared to normal tissue [3].

For a valid analysis of an infrared image sequence, however, a correct realignment of the images is fundamental. Otherwise, fluctuations in temperature caused by the fact that the subject is moving may confound effects due to anomalies in perfusion, as temperature samples corresponding to different skin regions are recorded as belonging to the same region. This effect may be critical to the point of invalidating the analyses, as differences in temperature of adjacent regions - corresponding in the time series to a single specific pixel (or group of pixels) - may be much higher than the perfusion phenomena of interest. This is especially true in areas in which a strong intensity gradient is present, e.g. above vasculature. The importance of compensating artifacts due to movement is shown in [4], where the power spectrum analysis of the non-realigned sequences (proposed in literature [3]) presents peaks which are due to movement artifacts. In fact, these same peaks disappear when image registration is applied to the sequence.

In [4] a first qualitative study of movement compensation is described. The aim of this paper is to further analyze this issue, by quantitatively evaluating the error correction introduced by alignment on a small sample of subjects. To realign the frames, a feature-based piecewise linear registration was employed. In feature-based approaches, the registration is obtained by realigning specific landmarks named control points [6]. To improve the registration, the images were upsampled by means of a bilinear interpolation. Different resampling factors were considered.

The paper is organized as follows: in Section II we describe the subject sample and the image acquisition, as well as the details of registration process, concluding with a description of registration evaluation. Furthermore, an algorithm for the automatic localization of the control points is proposed. In Section III obtained results are shown and discussed, while Section IV concludes and proposes future

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developments.

II. Materials and Methods

A. Image Acquisition

The infrared image sequences were acquired with an AIM Long Wave Quantum Well Infrared Photodetector (LQWIP 256) camera with a 50 mm optical focal length. Each thermographic sequence was composed of 476 images of 256x256 pixels, acquired at a frame rate of 100 frames/s. A frontal view comprehending both breasts was acquired.

A series of spherical polysterene markers were employed as features for registration and as test points for registration evaluation, as they are thermically stable and offer good contrast against the skin. 16 markers were used for registration, 7 around each breast contour plus two on the sternum. For the evaluation, a grid of markers internal with respect to this contour was added. An evaluation marker was also added on each nipple. In Figure 1 an example subject is shown. Subjects were asked to remain in apnea during the acquisition process in order to reduce movement.

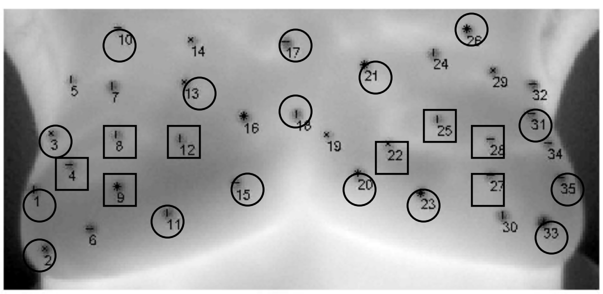

Fig. 1. Single infrared frame: markers used as control points are surrounded by circles, test markers used for registration evaluation by squares.

B. Automatic Marker Localization

The first step in any feature-based registration is the correct detection of the control points which are used to compute the registration tranformation. To localize the markers, an algorithm for the automatic detection of these markers was designed.

The control point detection algorithm consists in the following steps:

- Lowpass filtering of the original image.
- Subtraction of the lowpass-filtered image from the original.
- Global threshold segmentation. The threshold was obtained by minimizing the intra-class variance (Otsu's method [7]).
- Post-processing of marker segmentation by hole filling in the binary image. A hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image [8].
- Discarding of clusters falsely identified as markers. Clusters corresponding to true markers, which are spherical, must be ellipsoidal (due to planar projection).
- Control point assignment. The centroid of each marker is taken as control point.

The same procedure was applied to the markers employed as test points for the evaluation of the registration procedure. The marker centroids are thus identified and numbered on each frame of the sequence. To avoid matching errors due to a different numbering of markers in successive frames, a matching function is employed, which numbers the markers in each frame in such a way as to minimize the distance between same-numbered markers in different frames.

The correct localization of the centroid location is dependent on the image resolution. Image upsampling does not actually increase image resolution, but it does impact the correct identification of the marker area and consequently the localization of the marker centroid. In order to evaluate the effective impact of this procedure in infrared images, three different resampling factors (upsampling factors 2, 4 and 8, as well as no upsampling) were employed. The lower bound on the localization error is determined by the resampling factor, however the true error is dependent on how faithfully the image interpolation is capable of reproducing correct temperature values, which is much more difficult to evaluate. Bilinear interpolation was used, as it is reported to offer the best trade-off between accuracy and computational burden [6].

C. Image Registration

After control point localization, a piece-wise linear transformation was applied. This transformation was chosen as it is reported to be appropriate for cases in which small geometric differences between the images are expected [9], as in this case. The transform is computed on the basis of 16 control points. The upsampling performed on the images in the localization process is maintained during the transformation, in order to achieve subpixel accuracy.

D. Registration Error Evaluation

For each recording, the displacement of marker centroids not used for realignment was computed (see Figure 1). These markers were used as test points. In the non-realigned sequences, these values quantify the local movement. In realigned sequences they express the residual movement not compensated by registration, since in the realigned images the markers should always be portrayed in the same pixel. In particular, for each marker, the displacement due to the residual movement was computed as the Euclidean distance between the marker centroid in the first frame and in the successive frames. The distance from the first frame was thus computed for each frame, for every marker. The displacements were computed both for the test point markers and for the markers used for the registration. In fact, although the latter do not give a good measure of the global registration performance, they may be employed for the evaluation of the marker localization procedure. The number of test point markers applied on each subject was dependent on subject breast size, with a minimum of 4 markers internal to the registration marker contour for each breast. Hence, for intersubject comparison, only 8 markers were used for every subject.

III. Results and Discussion

The registration procedure was evaluated on a case sample of 10 menopausal women with no history of breast cancer and ages 57-69. The maximum displacement on the non-realigned sequences (computed both on frames and on markers) ranged between 0.7 and 5.3 pixels depending on the subject (results obtained with resampling factor 4, similar results for the other resampling factors), while the intramarker maximum displacement range was between 0.3 and 1.7 pixels. In Figure 2 the boxplot shows range, upper and lower quartiles and median for the distribution of the maximum displacement in time obtained on the test markers for each subject on the non-realigned sequences (thicker line boxplots, see figure legend). In Figure 3 quartiles and range are shown (thicker line boxplot, see figure legend) for the distribution of the displacements in time for the markers used successively both as control points and evaluation points for the subject shown in Figure 1.

In order to evaluate the registration process, as mentioned in Section II D, the centroid distance from the first frame

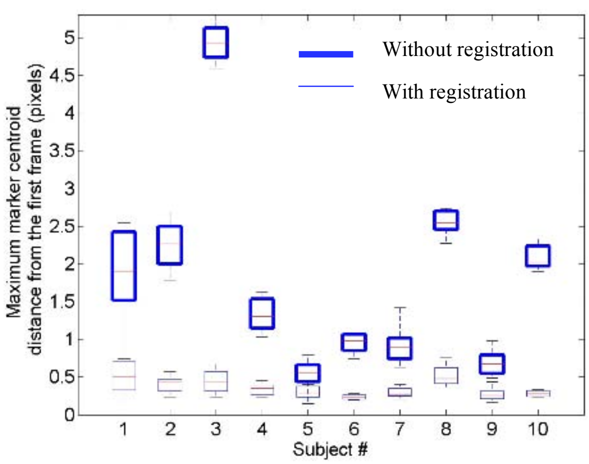

Fig.2. Boxplot of the marker centroid distance from the first frame before (thick line boxes) and after (thin line boxes) registration for ten different subjects. For each marker, the maximum distance in the time sequence was computed; for each subject the distribution of these (maximal) distances is shown. The reported results were obtained on the test point markers. The resampling factor used was equal to 4.

was analyzed separately for control point markers and test point markers. In Figure 4, the displacements for the realigned sequences at each time frame for two markers, i.e. marker #15 (realignment control point) and marker #8 (test point), for the example subject shown in Figure 1. The distances shown were computed for all 476 frames and for

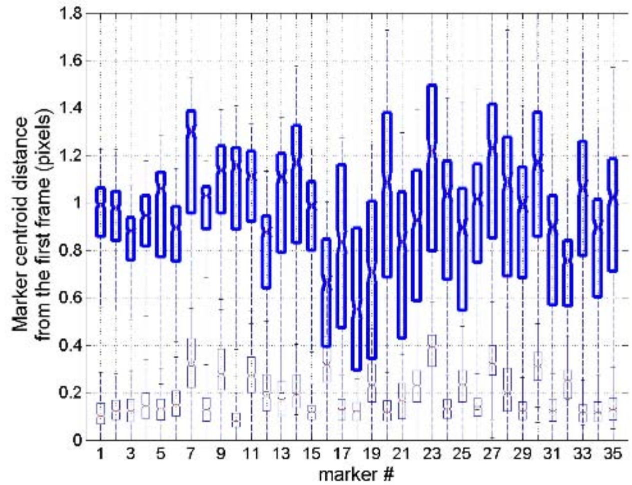

Fig. 3. Box plot of the time distribution of the marker centroid distance from the first frame before (thick line boxes) and after (thin line boxes) registration for the subject of Fig. 1. The resampling factor used was equal to 4.

all the resampling factors. Observing the figure, it may be noticed that while resampling factors 4 and 8 show the same trend, no resampling yields worse performances. Similar results apply to the other markers and the other subjects.

Further examining the example case shown in Figure 4, a trend may be seen in the test point markers, which is absent in the control point markers. Furthermore, both on control points and test markers an additive error term may be observed. It is thus reasonable to suppose that the trend is a measure of the realignment error in the registered sequences, while the added variance is due to the localization error. By

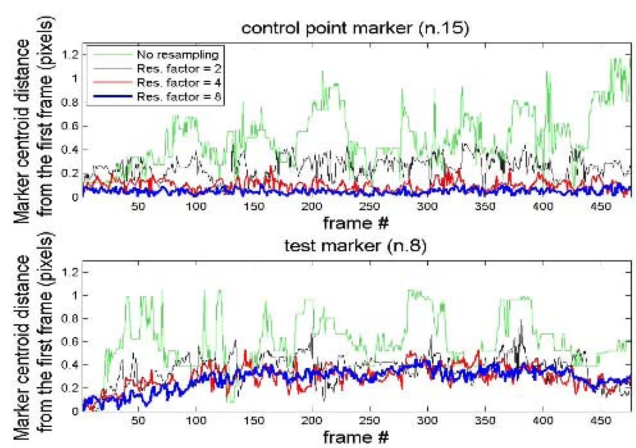

Fig. 4. Marker centroid distance from the first frame for different resampling factors: a control point marker (upper figure) and a test point marker (lower figure) for the subject of Fig. 1 (color image).

localization error we indicate the error committed in precisely identifying the markers' centroids' coordinates, while the alignment error is defined as the difference between the mapping model and the actual between-image geometric distortion [6].

In Figure 5 the standard deviation of the additive (localization) error term, is shown for the different subjects and resampling factors.

Globally, the registration ensures that the maximum marker distances are always inferior to one pixel and that the mean value computed for each subject is always less than 0.51 pixels, even in the worst case, i.e. movement above 5 pixels. These results are shown in Figure 2 (thin line boxplots, see figure legend), where the distribution of the maximum centroid distance from the first frame on registered sequences for all subjects are depicted (resampling factor 4). The maximum centroid distance here refers to the largest displacement from the first frame which

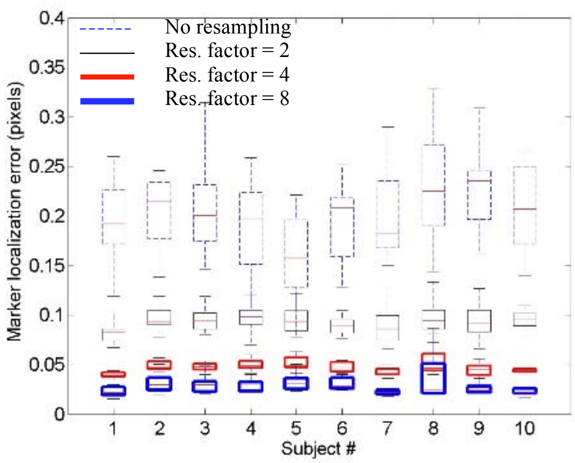

Fig.5 Marker localization error for different resampling factors (color image).

is obtained for each marker.

IV. Conclusions and Future Work

In this paper we presented results obtained by performing piece-wise linear registration of dynamic infrared images on a small sample of subjects. A feature-based registration approach was employed, with use of polysterene markers, which are automatically detected by an algorithm here proposed. Subject movement of up to around 5 pixels was corrected, obtaining a subpixel residual error. Analysis of the error term suggests the presence of two different components, which were explained as the alignment and localization error terms. The impact of the resampling factors on these errors was examined. Although the localization error was inferior for resampling factor 8 than for resampling factor 4, performances on alignment were comparable for the examined set of markers.

This work provides a first quantitative evaluation of the performances of alignment on dynamic infrared images. This preprocessing step may be very important for a correct analysis of the sequences, as we have shown in previous work [4]. Many issues remain to be clarified, such as the impact of the number and position of registration markers. Others kind of registration should also be evaluated, in order to allow the choice of the optimal transformation. We are working at all these issues and hope that this work will incite other groups also to make further contributions to this area which be believe to be fundamental for a true evaluation of the possibilities of dynamic infrared imaging.

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