Restoration of compressed or constricted images: A feasibility study for intra- and inter- imaging modality registration

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Purpose:

Human anatomy is largely made up of soft tissue and hence is elastic and deformable. Correlating information acquired from multiple scans, using the same imaging or different imaging modalities, is challenging. If ever possible, the combined modality such as PET-CT and SPECT-CT is preferred to take images from co-registered anatomy. For longitudinal follow-up studies, co-registration is still needed to allow for accurate comparison of changes. Numerous solutions have been reported in the literature to address the co-registration problem. Differences in grayscale and image resolution can be addressed by using an appropriate cost function, and shape variations can be addressed by using non-rigid transformations for obtaining a best fit warp. However, the validity of these algorithms in addressing large deformations, such as compression, has not been documented. Soft tissues, such as breast [1], urinary tract, intestines [2], liver, and other deformable organ, are more likely to suffer from large deformation or compression thus can benefit from the image restoration. At our institution, we have been developing a combined MR-SMM (scintimammography) system for early diagnosis of breast cancer. Data acquisition in the SMM system requires that patients with breast sizes larger than 10 cm be compressed so the entire tissue volume can be covered within the sensitive imaging field. As such the co-registration of the compressed breast (for SMM) to that of uncompressed breast (for MRI) is required for co-localization of the obtained functional and structural information. The automatic registration technique versus landmark-based methods were applied to restore deformations, and compared. A phantom with internal landmarks was used for evaluation of the restoration quality.

Methods:

Gelatin phantoms with an organized set of markers were built in the study. The markers were made of natural rubber, 3mm in diameter. A mechanical arm was attached to the device to control extent of compression. The experiments were performed on a 4T MR system, using the spin-echo pulse sequence. Field-of-view and slice thickness were set to 240mm and 2.5mm respectively. The phantom was placed in the compression device and multiple datasets with 20-30% compression rates were acquired. Scan time was approximately 40 minutes for each set.

The datasets were tested against automatic registration algorithm based on B-spline free-form deformation models, and landmark based free-form deformation using B-splines. Compressed MR data formed the target volume and uncompressed MR data formed the reference volume. Automatic registration algorithm warps the target volume so as to optimize the mutual information cost function whereas the landmark based registration algorithm is provided with an initial configuration of known mappings. Displacement vectors of the natural rubber markers are incorporated into the b-spline control net deformation as follows: for two corresponding points A and B (see figure 1), where A belongs to the floating image and B belongs to the reference image, the deformation force is $\vec{b} - \vec{a}$ in the direction of B, where $\vec{a}$ and $\vec{b}$ are vectors. The free-form deformation equation 1 is given below:

$$I(u,v,w) = \sum_{i=0}^{n_x} \sum_{j=0}^{n_y} \sum_{k=0}^{n_z} N_{i,p}(u) \,.\, N_{j,q}(v) \,.\, N_{k,r}(w) \,.\, P_{ijk}$$

$$where \quad : N_{\alpha,\beta}(\phi) = \frac{\phi - \phi_\alpha}{\phi_{\alpha+\beta} - \phi_\alpha} N_{\alpha,\beta-1} + \frac{\phi_{\alpha+\beta+1} - \phi}{\phi_{\alpha+\beta+1} - \phi_{\alpha+1}} N_{\alpha+1,\beta-1}$$

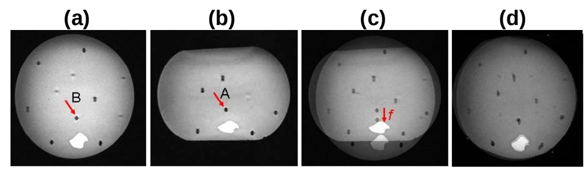

Fig.1: (a) source phantom, (b) after 25% compression, (c) superimposition of a and b, (d) superimposition of de-compressed b and a.

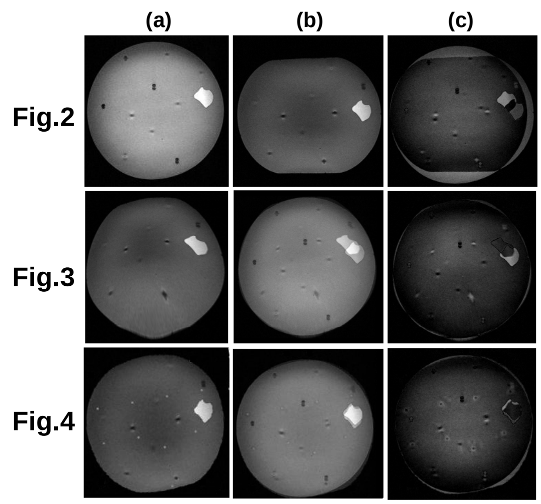

Fig.2: (a) source uncompressed phantom, (b) after 25% compression, (c) superimposed. Fig.3: (a) transformation of compressed image with automatic registration (b) superimposed original image Fig.2a and transformed image Fig.3a, (c) RMS error showing mis-registration at tumor site. Fig.4: (a) transformation of compressed image using landmark based b-spline deformation, (b), superimposed original image Fig.2a and transformed image Fig.4a, (c) RMS error was much smaller

Results:

Figure 1 shows the coronal uncompressed and compressed images generated from the phantom. A steady force leading to a 25% compression was applied to the phantom. Tumor is indicated by bright signal intensity. A free-form model was generated using equation 1 and the pre-defined mappings were incorporated. Fig.1d shows the results from de-compressing Fig.1b and superimposing upon Fig 1a. It may be noted that compression causes a spatial shift not only in the x-y plane but also between slices. This effect is most visible in the dislocation of the markers in the corresponding slice from compressed phantom. Figures 2-4 shows the results of de-compression applied to a second dataset, in which the tumor is located closer to the movable compression plate. The elasticity of the phantom is greater than the elasticity of the tumor; nevertheless we notice a slight deformation in the shape of the tumor besides the relative displacement of the entire phantom constituents. Fig.2 shows the source images, Fig.3 shows the results from automatic registration. As seen from the RMS error in Fig.3c, while decompressed boundary maps well to the source phantom, the registration accuracy is compromised at tumor margins, which occupies a very small part of the phantom. Fig.4 depicts the transformation using landmark based free-form deformation. A histogram analysis of the RMS error indicates that approximately 75% of the signals from transformed image map perfectly with those of the reference image. 94% of the pixels are off by a small margin of 20%, and less than 0.08% have differences greater than 100 intensity levels on a scale of 0-255. The tumor outlines also match well with the source tumor locations.

Discussion:

We have described the differences in automatic and landmark based registration schemes to restore the image of an anatomy that is subjected to significant deformations either due to applied force or due to natural aesthetic changes. Automatic registration algorithms are biased towards dominant regions and this leads to incorrect tumor margins in the reference scans. On the other hand, our variation of landmark based method that incorporates pre-defined mappings into the free-form deformation model, helps to appropriately weigh the degree of alignment towards regions of higher relevance. The near future application of the developed method is for co-registration of breast images acquired using MRI (uncompressed) and scintimammography (under light compression).

References: [1]. Martincich L. et al, Journal of BCRT, Vol. 83, 2004, pp. 67-76. [2]. Vries, A. H. et al, BJR, Vol. 79, 2006, pp. 740–744.
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