Registration of Mammograms and Breast Tomosynthesis Images

Predrag R. Bakic[1], Frederic J.P. Richard[2], and Andrew D.A. Maidment[1]

[1] University of Pennsylvania, Philadelphia, PA
{Predrag.Bakic, Andrew.Maidment}@uphs.upenn.edu
[2] Universite Paris 5, Paris, France
Frederic.Richard@math-info.univ-paris5.fr

Abstract. Digital breast tomosynthesis is becoming a clinically attractive modality based on its potential to combine the high resolution and high contrast images, and affordability of digital mammography, with the advantages of 3D image acquisition. In order to facilitate comparison of tomosynthesis images with previous mammographic exams of the same women, there is a need for a method of registering a mammogram with a tomosynthetic image of the same breast; this is the focus of this paper. We have chosen to approach this multimodality registration problem, starting from the simpler problem of registering a mammogram and the central tomosynthesis source image. Such a registration pair represents the most similar breast images obtained from different clinical modalities. In this study of 15 pairs of mammograms and central tomosynthesis projections of the same breast, on average we were able to compensate 94 percent of the per-pixel intensity differences that existed between the two images before the registration.

1 Background

Early breast cancer detection requires identification of subtle pathological changes over time, and is often performed by comparing mammograms from previous years. Those changes can be masked by breast positioning, compression, or x-ray acquisition parameters. Similarly, multimodality breast images are acquired with different positioning, compression levels, and they also measure different material properties. An approach to compensate for the acquisition related variations is image registration, in which one image is deformed in order to match another image, based on some similarity criterion. Registration could improve the accuracy of temporal or intermodality comparison, and potentially emphasize genuine tissue alterations.

Tomosynthesis is a novel x-ray based modality for imaging 3D breast anatomy. First, a small number of projections through the compressed breast are acquired, while varying the position of the x-ray focus. By combining information from these projections one can gain information about the 3D tissue distribution. Several algorithms have been proposed, ranging from relatively simple backprojection techniques to sophisticated algebraic reconstructions [1,2]. While the limited number of projections prevents CT-like reconstruction quality, our clinical experience has

Susan M. Astley et al. (Eds.): IWDM 2006, LNCS 4046, pp. 498 – 503, 2006.

confirmed our ability to produce images in which a given anatomical plane is in focus while anatomical structures above and below the plane are blurred to such an extent as to be essentially removed from the image (*see Fig 2*).

Tomosynthesis is becoming a clinically attractive modality based on its potential to combine high resolution and high contrast images, and affordability of digital mammography, with the advantages of 3D breast image acquisition. In addition, there is a potential for functional imaging, in the form of contrast-enhanced tomosynthesis [3]. In order to facilitate comparison of new tomosynthesis images with previous mammographic exams of the same women, there is a need for a method of registering tomosynthetic and mammographic images, which is our focus in this paper. To the best of our knowledge, there has been no report in the literature on this specific multimodality registration problem.

In this paper we present the results of registering 15 pairs of mammograms and central tomosynthesis projections of the same breast.

2 Materials and Methods

There are two aspects to the problem of registering mammograms and tomosynthesis images: (i) Registration of a mammogram onto a tomosynthesis reconstructed volume of the same breast is a 2D-3D registration problem. (ii) Registration of an individual tomosynthesis reconstructed plane onto a mammogram is a 2D-2D problem. Such a task, however, cannot be performed by simply extending the existing mammogram registration methods, since the size and content of the breast portion within an individual reconstructed plane vary depending on the slice position. Although both images have the same physical nature, their acquisition procedures (projection vs. tomographic reconstruction) are substantially different.

As a preliminary step, in this paper we describe registration of a tomosynthesis central source projection and a medio-lateral mammogram of the same breast. The central projection is acquired in a medio-lateral (MLO) breast positioning with reduced dose and compression.

2.1 Clinical Data

At our institution, tomosynthesis source images are acquired on a Senographe 2000D (General Electric Medical Systems, Milwaukee, WI) which has been modified to allow independent motion of the x-ray tube head and removal of the anti-scatter grid. The x-ray tube can be reproducibly positioned at 9 locations, each separated by approximately 6.25°. Each breast is compressed in an MLO position. The source images are acquired at a total dose equal to that of two MLO mammograms. Tomosynthesis breast images are reconstructed in planes parallel to detector, using a modified backprojection algorithm. To date, 51 clinical breast tomosynthesis exams have been performed under IRB review as a part of a large multimodality clinical study in our department. After informed consent, all the patients in the study were offered tomosynthesis, mammography, breast MRI, PET, and ultrasound exams. For each tomosynthesis image there is a corresponding mammogram taken on the same day by the same x-ray technologist, thus having minimal variations, which is of importance for initial testing of the registration methods.

In this study we performed registration of 15 pairs of mammograms and central tomosynthesis projections, from ten women (mean age 48.4 years; age-range 39-62 years) imaged between August 2004 and May 2005 at the Hospital of the University of Pennsylvania. Four out of these ten women had confirmed malignancies, five had findings suspicious for malignancy, and one had a benign finding. The selection criteria was that the whole breast was well visible in both the MLO mammogram and the central tomosynthesis projection. Such a criteria excluded cases of very large breasts, in which several images had to be taken to cover the whole breast in the MLO positioning. We also excluded cases with low quality of the tomosynthesis projection images, due to excessive patient motion or problems with breast positioning.

2.2 Non-rigid Registration Method

For the registration of mammograms and central tomosynthesis source images, we have used a recently developed non-rigid registration method [4]. The method focuses on matching regions of interest (ROIs) in source and target images of a registration pair, and combines intensity- and contour-based constraints. The registration task is formulated as an inverse problem of finding a geometric deformation that minimizes an energy function with free boundary conditions. The energy function includes three constraints designed (i) to provide for regularization and prevent ill-posed problems, (ii) to compensate for linear variations in image intensities, and (iii) to correct initial mapping of target image ROI onto the source image ROI.

Before the registration, the ROIs were identified as the breast regions without the pectoral muscle. The pectoral muscle area was identified as the region above the line defined by two manually selected points on the muscle contour. In this study, we registered the two images by deforming the mammogram to match the central tomosynthesis projection of the same breast. The non-rigid registration method was performed in two steps: First, an initial registration was performed, based on the contour matching only. This initial step is followed by the corrections of the differences in the pixel intensity distribution between the target and source images. Detailed description of the registration method is given in our previous publications [5]. In an evaluation using synthetic images generated with a software breast model [6], the ability of this registration method to compensate for variation in compressed breast thickness has been demonstrated [5].

In the present study of clinical images, we evaluated the registration results by the analysis of pixel intensity differences, using the percent of corrected differences as a measure of the registration performance. The percent of corrected quadratic differences, PCQD, is defined as:

$$PCQD = [\Sigma_{ij}(\Delta_{ij}^{PRE}) - \Sigma_{ij}(\Delta_{ij}^{POST})] \,/\, \Sigma_{ij}(\Delta_{ij}^{PRE}) \qquad (1)$$

where Δ_{ij}^{PRE} and Δ_{ij}^{POST} represent the quadratic differences between the intensities of the pixels at position (i,j), before and after registration, respectively. $\Delta_{ij}^{P}=[(M(i,j)^{P}-CT(i,j)]^{2})$, where $M(i,j)^{P}$ represent the intensity of the pixel at postition (i,j) in the mammogram before (P=PRE) or after (P=POST) registration, and $CT(i,j)$ represent the intensity of the pixel at position (i,j) in the central tomosynthesis projection. The higher PCQD values indicate the better registration performance.

In addition, we compared the root-mean-square (RMS) differences between the mammograms and central tomosynthesis projections, computed before and after the non-rigid registration.

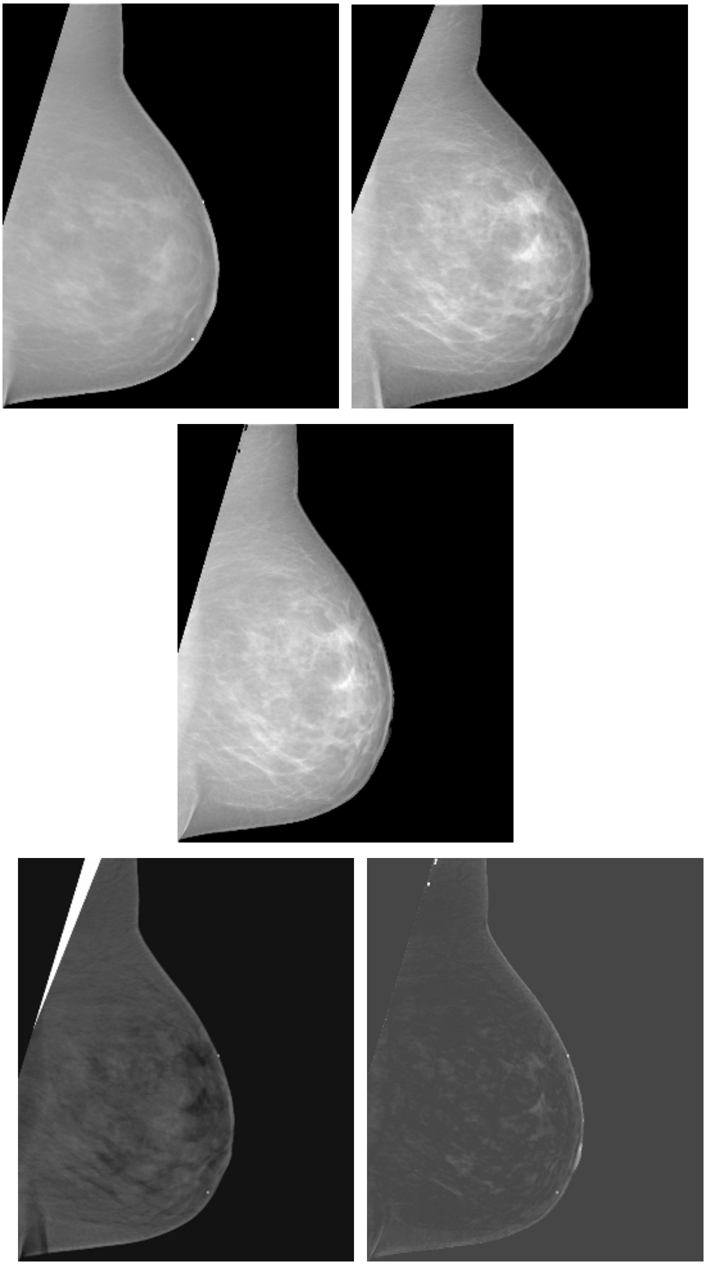

Fig. 1. The upper row shows the registration image pair: a mammogram (left) to be registered onto a tomosynthesis source image of the same breast (right). The registration result is shown in the middle row. The lower row shows the difference between the mammogram and central tomosynthesis projection, computed before (*left*) and after (*right*) the registration.

3 Results

Fig. 1. shows an example of registration of a mammogram and the central tomosynthesis projection of the same breast. Shown are the mammogram (upper left) and the corresponding central tomosynthesis projection (upper right). The registration result is shown in the middle image as well as the difference images, computed before (lower left) and after (lower right) the registration. For all 15 image pairs we computed the PCQD measure of the registration performance (defined in Section 2.3) after the initial and after the complete registration. The average PCQD values (±standard deviations) were equal to 52±20% and 94±3%, after the initial and complete registrations, respectively. Fig. 2 shows a plot of the RMS differences between the mammograms and central tomosynthesis projections, computed before and after the non-rigid registration.

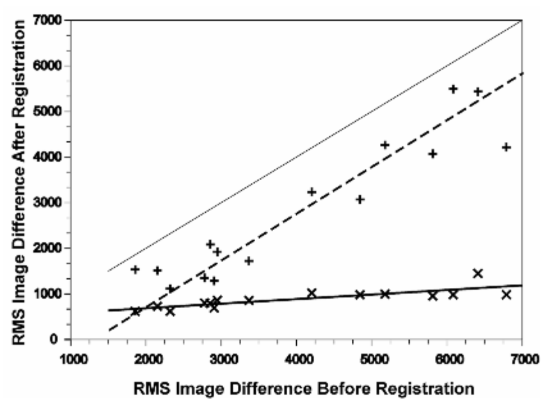

Fig. 2. RMS differences between the mammogram and the central tomosynthesis projection, computed before and after the registration. Shown are the RMS differences after the initial (+) and after the complete registration (×). The corresponding linear regressions are plotted by the dashed and bold lines, respectively. The solid unity line indicates zero registration performance.

4 Discussion

We have chosen to approach the registration of a mammogram and a tomosynthesis image of the same breast, starting from the simpler problem of registering a mammogram and the central tomosynthesis source image. Such a registration pair represents the most similar breast images obtained from different clinical modalities.

The computed average PCQD values suggest that the initial registration step and the remaining registration step contribute approximately equally to the correction of image differences.

Fig. 2 shows that after the initial registration step the difference between the registered images is proportional to image difference before the registration. After the complete registration, the image difference practically does not depend on the differences observed before the registration. In this paper, we evaluated the registration performance based on the pixel intensity differences. In future work we plan to evaluate the registration results based on the average displacements of manually or automatically extracted fiducial points.

Presently, we have considered registration of MLO mammograms with central tomosynthesis projections, since the latter are also acquired in the MLO positioning. Registration of a CC mammogram with the tomosynthesis images would require to computationally “decompress” the breast from the MLO position and “recompress” it in the CC position. Techniques allowing such transformations have been reported in the literature [7]. Novel methods could be developed by utilizing the 3D nature of tomosynthesis images.

5 Conclusions

We performed a non-rigid registration of 15 pairs of mammograms and central tomosynthesis projections acquired from ten women. The mammograms and tomosynthesis images were acquired on the same day by the same technologist, thus having minimal variations. We evaluated the registration performance by computing the percent corrected quadratic differences between the mammogram and the central tomosynthesis projection. On average we were able to compensate 94 percent of the per-pixel intensity differences that existed between the two images before the registration.

Acknowledgement

The presented work was supported by the National Cancer Institute Program Project Grant PO1 CA85484.

References

1. Niklason, L.T., Christian, B.T., Niklason, L.E., Kopans, D.B., et al.: Digital Tomosynthesis in Breast Imaging. Radiology. 205 (1997) 399-406
2. Maidment, A.D.A, Albert, M., Conant, E.F.: Three-dimensional Imaging of Breast Calcifications. In Proc. SPIE 3240 (1998) 200-208
3. Carton, A.-K., Li, J., Albert, M., Chen, S., Maidment, A.D.A.: Quantification for Contrast-enhanced Digital Breast Tomosynthesis. In Proc. SPIE 6142. (2006)
4. Richard, F.J.P., Cohen, L.: Non-rigid Image Registration with Free Boundary Constraints: Application to Mammography. Comp Vis Image Understanding 89 (2003) 166-196
5. Richard, F.J.P., Bakic, P.R., and Maidment, A.D.A.: Mammogram Registration: a Phantom-Based Evaluation of Mammographic Compression Effects. IEEE Trans Med Imag. 25 (2006) 188-197
6. Bakic, P.R., Albert, M., Brzakovic, D., Maidment, A.D.A.: Mammogram synthesis using a 3D simulation. I. Breast tissue model and image acquisition simulation. Med Phys. 29 (2002) 2131-2139
7. Kita, Y., Tohno, E., Highnam, R., Brady, M.: A CAD system for the 3D locations in mammograms. Med Image Anal 6 (2002) 267-273