Model–based Registration of X–ray Mammograms and MR Images of the Female Breast

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***Abstract*— We present a new approach for automatic registration of X–ray mammograms and MR images. Multimodal breast cancer diagnosis is supported by automatic localization of small lesions, which are only visible in the mammograms or the MR image. To cope with the huge deformation of the breast during mammography, the model–based registration is carried out by deforming a finite element model of the breast.**

An evaluation of the registration with six clinical data sets resulted in an accurate localization with a mean displacement of 4.3 mm (± 1 mm) and 3.9 mm (± 1.7 mm) for predicting the lesion position in mammograms and in the MR images, respectively.

I. Introduction

A. Problem Statement

The central problem in registration of (X–ray) mammograms and MR images is the unknown three–dimensional (3D) deformation of the breast applied during mammography. To obtain a mammogram, the breast is subjected to the so–called plate compression, where it is squeezed between two plates with up to 50% decrease in diameter. This complex 3D deformation of the breast is only recorded as one 2D projection, so that the individual 3D configuration of the deformed breast cannot be reconstructed. The deformation of the breast is patient specific because the breast's shape and composition, the patient's position, the deformation thickness and applied force varies highly between patients.

B. State Of The Art

Only three approaches for registering mammograms and MR images have been proposed until now [1]–[3]. All approaches registered mammograms with direct projections of the undeformed breast in the MR image. Therefore the 3D effects of the deformation are not included.

C. Rationale

We developed a novel registration method for two mammograms and a MR image. This registration includes a biomechanical model of the deformable behavior of the breast to overcome the problems associated with the huge deformation during mammography. This model allows to deform the undeformed breast in 3D, as given in the MR image, to get the same configuration as in a corresponding mammogram. Thus a subsequent projection of the deformed MR image includes the 3D effects of deformation and can be compared directly to the mammogram.

The method permits to locate the 3D position of suspect lesions, which are only visible in the mammograms, within the MR image, or vice versa. Our aim is to match mammograms and MR images with a maximal displacement of 5 mm, which is the size of the smallest visible lesions in conventional MRI.

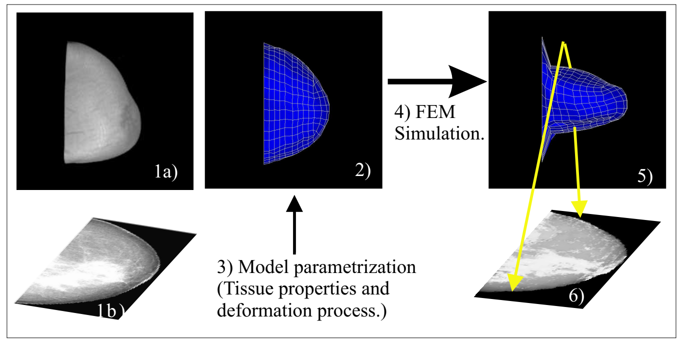

Fig. 1. Registration strategy: 1a) MR image and 1b) mammogram. 2) Patient specific finite element mesh. 3) Formulation of the tissue properties and the deformation process. 4) Simulation. 5) Generated MR image of deformed breast and 6) subsequent projection.

II. Methodology

A. Simulation of the Mammographic Deformation

The geometry of the simulation model is individually constructed based on the breast imaged in the MR image of a specific patient. The different tissues of the breast are included in the model by simulating their particular physical properties. Then the details of the deformation process are expressed, e.g. as plate compression. After building this model, the deformation is simulated using the finite element method for large deformations and non–linear (nearly) incompressible materials. The results of the simulation are subsequently used to generate an artificial MR image of the deformed breast and a corresponding projection. A summary of this registration strategy is given in figure 1.

B. Model–based Registration

Registration provides the direct comparability of the matched images. This is ensured by the appropriate formulation of the simulated deformation process, adjusting the deformed breast of the simulation to the deformed breast in the corresponding mammogram.

First the exact projection angle and the imaged portion of the breast in the mammogram are calculated to align the images globally, using our earlier registration approach [1].

Second, the simulation model is built as described above and the deformation simulation is carried out as follows.

We showed (see results), that simulations driven by a deformation formulation, which warps the 3D breast surface to the shape of the deformed surface give the best overall similarity. Since the 3D shape of the deformed breast is not recoverable from the mammograms, this problem is solved using a two–step approach. In the first step the model of the breast is subjected to a deformation simulating mammographic plate compression. In the second step, the shape of this deformed breast and the circumference of the corresponding mammogram are used to estimate the 3D shape of the breast surface during mammography. This estimated surface deformation is applied as simulation constraint. The simulation results in a MR projection with exactly the same circumference as the mammogram.

C. Localization of a Lesion

To recover the position of a lesion in the mammogram, its known position in the MR image is projected from the simulated deformed MR image. The projected position can be transferred directly to the registered mammogram.

To recover the volume in the MR image containing a lesion known in the two standard mammograms, the registration approach described above has to be accomplished for both mammograms. After the registration, the position of the lesion in the mammogram can be superimposed directly onto the particular MR projection. Knowing the deformation applied to the undeformed breast, the actual position of the lesion in can be calculated by applying the inverse transformation.

III. Results

A. Parameters of the Deformation Model

Different physical models for breast tissues and different formulations of the deformation process were examined to obtain an adequate simulation model, which satisfies the requirements for accuracy. A specially acquired data set was used, consisting of two MR images of a healthy volunteer, one displaying an undeformed breast, the other showing the same breast, subjected to mammographic compression. We demonstrated, that a simulation model with the same physical tissue properties for all breast tissues is sufficient, and more complex models do not increase the simulation accuracy [4].

Simulations using only plate compression for deformation formulation gave a mean displacement error of 3.7 mm (standard deviation $\pm$1.3 mm). However, the maximal displacement was slightly larger than the accuracy limit of 5 mm. Simulations using additional information about the 3D surface deformation to drive the compression had an overall accuracy of 2.6 mm ($\pm$1.1 mm). The maximal error was well below the limit of 5 mm.

B. Localization Accuracy with Clinical Data Sets

An evaluation of the localization accuracy of the model–based registration with six clinical data sets resulted in a mean displacement of the center of a lesion of 4.3 mm (standard deviation $\pm$1 mm) for predicting the lesion position in mammograms, and a mean center distance of 3.9 mm ($\pm$1.7 mm) estimating the lesion position in the MR images. This equals an improvement of 78% and 94% compared to a simple rigid registration. Exemplary results are displayed in figure 2.

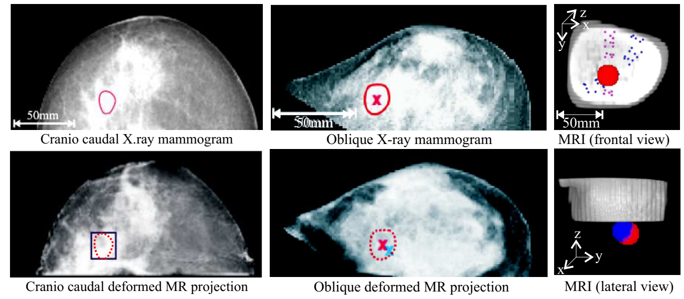

Fig. 2. Exemplary localization results. First two columns show mammograms and the corresponding MR projections with lesion localization. The third column depicts the lesion localization in a MR image. The original lesions are depicted in red, the localization in blue.

IV. Discussion and Conclusion

We developed a new model–based method to register mammograms and MR images of the breast, which overcomes the problems due to the huge deformation of the breast during mammography. It enables to automatically determine the relationship between the mammographically deformed breast and the undeformed breast.

The accuracy of the registration showed in a first evaluation with six clinical data sets to be sufficient to locate even the smallest visible lesions. In all cases the estimated center of the lesion lay within the actual lesion area or volume and is therefore adequate for biopsy. These very good results will be evaluated in a clinical study with a larger set of data.

Possible applications of this approach are support of biopsy or surgical interventions, e.g. MR image guided biopsy of lesions only visible in mammograms, or to combine the diagnostic information of mammograms and MR image, e.g. diagnosis support or comparative studies.

References

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