Elastic Registration of X–Ray Mammograms and Three–Dimensional MRI Data

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Abstract

Major problems in treating breast cancer are the early detection of tumors and accurate biopsy of small volumes of breast(mamma) tissue. This paper presents an elastic registration algorithm of two X–ray mammograms and a corresponding MRI volume. To cope with the soft tissue deformation of the breast during mammography, a two–dimensional model of breast deformation behavior is used as an elastic transformation. Normalized mutual information is employed as a measure of similarity. Regions of interest in the uncompressed X–ray mammograms are projected into the MRI volume to determin their three–dimentional origin.

Keywords

Elastic registration, normalized mutual information, breast MRI, X–ray mammography

1 Introduction

Breast cancer is one of the most dangerous types of cancer. One in eleven women in the Western world is affected during her lifetime. The main causes of death arise from difficulties in early diagnosis because it is crucial, for successful therapy, to detect breast cancer before external metastases are produced [1]. The most common method of breast cancer detection, next to palpation, is X–ray mammography. For all diagnostic benefits, X–ray mammograms have the disadvantage of showing a deformed mamma. To obtain a mammogram, the breast must be squeezed between two plates. For further treatment, e.g. biopsy or surgical planning, or for combination with other imaging methods, e.g. Magnetic Resonance Imaging (MRI), it is important to determine the relationship between the undeformed and the deformed mamma.

In this paper, a method of matching two X–ray mammograms to an MRI volume of the same, but undeformed, breast is proposed. This allows the three–dimensional position of suspect regions (lesions) only visible in X–ray mammograms to be localized within the MRI.

2 Registration of Multimodal Breast Images

Registering images of deformed mamma tissue is a difficult task because the female breast consists of deformable, mobile, inhomogeneous tissue, deforms varyingly [5], and offers no internal structures (landmarks) discernible in each multimodal picture, e.g. X–ray mammograms and MRI.

In this approach, the behavior of the mamma is simulated by a deformation model.

2.1 Modeling Compression

A limited number of studies concerned with the effects of deformation during mammography have been carried out so far.

Novak [2] analyzed the use of markings applied to breasts during mammography. He successfully carried out approx. 100 biopsies based on two X–ray mammograms according to his findings.

The results of that study are used to build our deformation model. The first assumption is that the relative distances of the tissue and the surrounding projection of the skin will remain the same during every compression process. Therefore, projections of the undeformed mamma displayed in the MRI volume are considered special cases of X–ray mammograms. Hence, the displacements of the inner structures can be calculated, depending on the behavior of the circumference of the projected breast. Another assumption is that of a declining angle to model the effects of gravitation and different patient postures at different mammographic projection angles. On these assumptions, our model provides a general relationship between different X–ray mammograms and the MRI.

2.2 Transformation

A transformation in two–dimensional space was developed for our registration algorithm to fulfill the compression model described above. An undeformed projection of the MRI is regarded as a special case of a compressed X–ray mammogram. Thus, the transformation matches the MRI–projection to make it look like the mammogram (the MRI–projection is “compressed” afterwards), or a mammogram to look like an MRI–projection (“uncompressed” mammogram). (See Figures 1 a) and c)) For compressing an MRI–projection, the transformation is carried out as follows: The MRI–projection is first scaled to match the length of the breast in the X–ray mammogram in the direction towards the chest. Then the circumference of the MRI–projection is scaled to the circumference of the X–ray mammogram. The inner structures are scaled non–linearly, which means scaling, for every (pixel) row with a different scaling factor, resulting from the differences in the circumferences in that row. Then the MRI–projection is compressed according to our model. In the neighborhood ($\pm 25°$) of the estimated real projection angle of the X–ray mammogram MRI–projections are compressed and their similarity to the X–ray mammogram is computed as described in Section 2.3. The projection angle, α_{max}, of the best match, and the elongation of the breast due to compression, furnish the spatial correspondence of one X–ray mammogram to the MRI volume.

2.3 Measure of Similarity

To overcome the different modalities, a measure of similarity is chosen which copes with the non–linear dependence of the different grey–value functions in MRI and X–ray images, different distributions of noise and unilateral absence of image structures. Studholme’s [4] robust normalized mutual information (NMI) was therefore used. As he states, NMI assumes that the most prominent regions of the images must be aligned. This assumption is violated by aligning a T_2–weighted MRI and an X–ray mammogram, because the fatty tissue is nearly invisible in an X–ray mammogram (dark grey), but prominent in MRI (bright grey). Hence, the fatty tissue must be segmented and removed from the MRI (Figure 1 b).

2.4 Back Projection

To locate the three–dimensional origin of a lesion two X–ray mammograms are required. First, the X–ray mammograms must be uncompressed. This is done the same way as the compression, but this time the circumference of the X–ray mammogram is scaled as shown in Figure 1 c).

The uncompressed X–ray mammograms are aligned to the MRI volume according to the parameters of the spatial correspondence. If the two X–ray mammograms display the same lesion, a beam vertical to the projection can be defined for each view. This beam would have imaged the lesion in an X–

ray mammogram of an uncompressed breast (Figure 2). The beams intersect at the three–dimensional position of the lesion within the MRI volume.

3 Results and Discussion of Registration Experiments

3.1 Phantom Experiments

Phantoms based on real MRI data were built to test the precision of the algorithm under the assumption, that the breast behaves as predicted in our model. Small lesions were defined within an MRI volume ($\geq (1.37mm)^3$ the resolution of the datasets) on the vertical axis towards the chest through the nipple, in the middle of every quadrant and near the breast outline. X–ray mammograms (projection angles of $-5°$, $0°$, $3°$, $10°$, $30°$, $45°$, $60°$) were simulated according to the compression model and the displacements of the lesions recorded. Noise, grey–scale transformations (e.g. random lookup tables) and imaging errors (e.g. parts removed from the inner structures) were added. After processing the phantoms with our algorithm all lesions were retrieved at their recorded locations down to the size of a voxel.

3.2 Experiments with Real Data

This approach extends the model by Novak insofar, as undeformed projections of MRI volumes can be treated the same way as X–ray mammograms. Thus, their relationship can be described in terms of the projection angle, elongation of the breast due to compression, and two–dimensional compression simulation. In order to validate this assumption experiments with three pairs of cranio–caudal(cc) and mediolateral–oblique(mlo) X–ray mammograms and an MRI volume were carried out, and the plausibility of the projection angles and the percentage of elongation of the breast due to compression were examined. $\alpha_{cc} = 0°$ is an estimated projection angle for cc (head to feet), and $\alpha_{mo} = \pm 45°$ is the estimated projection angle for an mlo (shoulder to opposite hip) X–ray mammogram. The projection angles are given as estimates, as the exact angles vary by $\pm 25°$ and are not recorded during mammography.
MRI–projections between $-180°$ and $180°$ in steps of $1°$ were matched to cc and mlo X–ray mammograms, respectively, and NMI was computed for each pair of an MRI–projection and an X–ray mammogram.
The results of this experiment (see Table 1) confirm the assumption that it is possible to match MRI volume and X–ray mammograms. The parameters of spatial relationship are plausible. The variation in dataset No.3 is caused by the fact that the whole trunk of the patient was rotated approximately $10°$.

4 Conclusion

Our approach shows very promising results in matching the MRI volume and X–ray mammograms, despite the compression applied to the breast during mammography.

The compression model employed is an averaging model because it does not deal with the inhomogeneous behavior of the different types of tissue. It assumes a homogeneous distribution of the compression force, which makes it a simplified model. For more detailed modeling, see a recent approach to modeling the breast by means of the finite element method [3], or an approach to modeling the nonlinearity of the deformation [6].

The averaging model makes this approach applicable to any patient, because no advance diagnosis is necessary. No time consuming, user involving preprocessing is needed for landmark detection or segmentation. This makes our approach promising for clinical application. It can be used to fuse MRI and X–ray data for multispectral diagnosis and help locate lesion within the MRI–volume which are only visible in X–ray mammograms.

A clinical study is planned to provide more detailed results in validation of our approach.

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Dataset#	Projection	α [°]	Elongation [%]
1	cc	9	5
1 (left breast)	mlo	-43	1.5
2	cc	8	7
2 (right breast)	mlo	50	2
3	cc	18	6
3 (left breast)	mlo	-30	2

Table 1: Table of spatial relationship parameters.

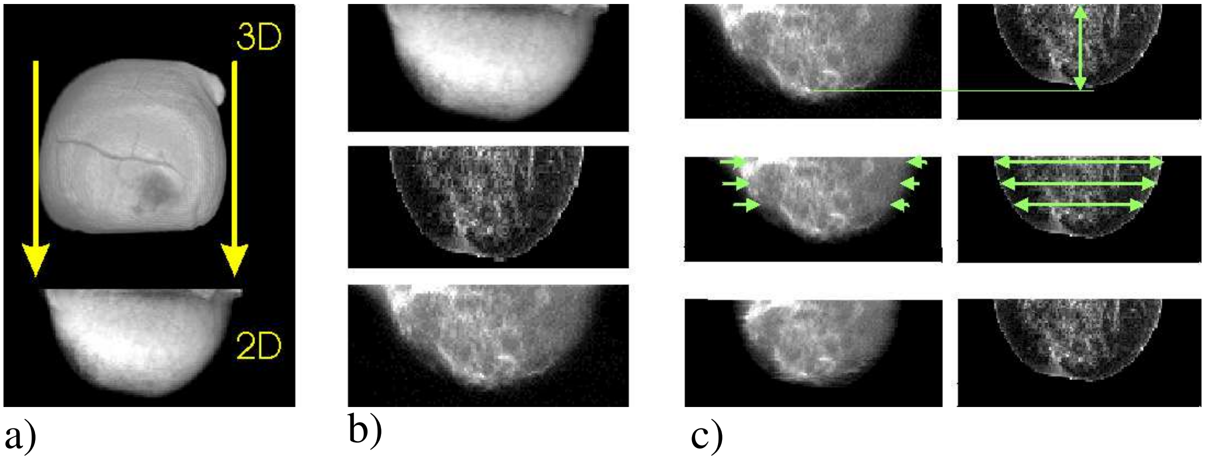

Figure 1: Steps of the matching process:

(a) Simulation of MRI–projection.

(b) Top: original MRI–projection; middle: MRI–projection without fatty tissue; bottom: corresponding cc X–ray mammogram.

(c) Example fof “decompression” of an MRI–projection. Top row: original cc X–ray mammogram and 0° MRI–projection. The arrow indicates the different lengths due to compression. Middle row: X–ray mammogram aligned to the length of the MRI–projection. The arrows indicate the different circumferences of the breasts. Bottom row: both images are aligned completely.

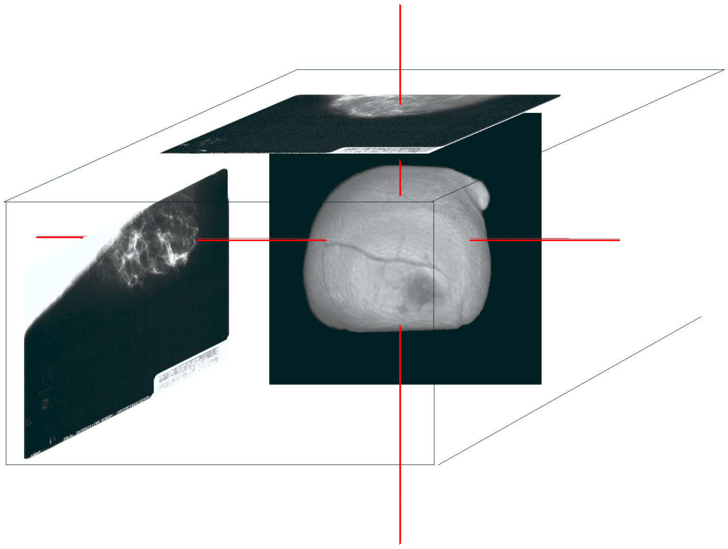

Figure 2: Example of back projection.

An MRI volume is set to spatial correspondence with two “decompressed” X–ray mammograms. The same lesion is identified in both X–ray mammograms and for each a beam is defined into the three–dimensional space. The beams intersect within the MRI at the lesion’s three-dimensional origin.