# On Compression Model for Integrative Analysis of Different View Breast Xrays

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***Abstract*— The breast deformation during medical procedures makes it difficult to analyze different breast images integratively. The simulation of the breast deformation is effective to compensate the difference of the breast shape among the images. However, realistic simulation is very difficult since the actual deformation is quite complicated and the detailed conditions about the deformation are hardly known mainly because of the large individual variations in both geometry and tissue organizations. For a CAD system for integratively analyzing different view mammograms (breast Xrays) [1], a simplified model to simulate the breast compression, which is derived base on several approximations about the deformation is used. Although it contributes to derive valuable results, the precision of the results is desired to improve. In this paper, we discussed about a breast compression model aiming at more accurate solutions. Two trials for better understanding on the breast deformation under the compression are shown: simulation of mammographic compression using a mechanical model and inspection of internal deformation using a devised phantom. These experimental results gave us some clues for better simulation.**

## I. INTRODUCTION

Breast cancer is one of the most serious disease for women. Recently, several types of medical images are used for screening programs to detect breast cancer in its early stages with less oversight. Especially, mammograms, MRI and Ultrasound are well used because of their good balance in trade-off between specificity/sensitivity and cost. It is effective to integrate the information obtained from different images, as each modality has its merits and demerits. However, it is not easy because a breast deformed into very different shapes during the procedures. For mammograms, a breast is strongly compressed into flattened shape primarily to reduce x-ray dosage. For taking MRI, the breast is pendulous in specially designed breast coil as the patient lies on her front in the magnet; the gravity pulled down the breast so as to get it away from her chest wall. On the other hand, since women lie on the bed with her face up during the ultrasound process, the breast shape is pulled toward the chest wall by the gravity.

It is a natural and sensible strategy to simulate the deformation of the breast to compensate the difference in the shapes among the images. At first, deformable models which deform so as that image features of the two different images coincide each other were used to compensate relatively small deformation, such as pre-post contrast MRI[2][3] [4]. Later, to decrease deformations inconsistent to the physics, constraints based on volume conservation principle were introduced[5][6].

For larger deformation as like seen in compression procedures, finite element models (FEM) of breast have been intensively studied recently aiming at accurate simulation[7][8][9][10][11][12][13]. However, FEM models can simulate accurate deformation only when all internal end external factors, such as geometry and biomechanics of the breast, forces exerted to the breast, and boundary conditions are given correctly. Unfortunately, in most of practical cases, it is quite difficult to grasp these information: geometry of the breast varies largely according to individuals; organization of internal soft tissues are also different among the individuals; both strength of compression and boundary condition at the connection of chest wall are very complicated.

Especially, in the case of integrative analysis of different view mammograms (breast Xrays), the input is only two projective images of differently deformed breast. To simulate the breast compression process for building a CAD (Computer Aided Diagnosis) system under such situation, Kita et al [1] introduced a simplified compression model based on several approximations. For appropriate simplification, it is important to understand the principle and tendency of the breast deformation under compression. Actually, the compression model was derived based on several clinical studies[14],[15]. Especially, Novak[15] studied deformations of the breast surface during compression by observing the movements of marks made on the skin of volunteers' breast. However, such observations only give information about skin movement, and do not strictly give information about movements of tissue internal to the breast. To improve the model, we need more investigations about the internal deformation caused by the compression.

In this paper, we showed some preliminary trials for better understanding of the breast deformation including its internal deformation to improve the compression model used in the CAD system. In Section II, we briefly explain the scheme of the CAD system and the compression model used in the current system. In Section III, the breast deformation by compression is investigated by comparing a mammogram and a MRI of the same breast through the intermediary of a mechanical model. In Section IV, the internal deformation by compression is investigated by observing a phantom in a industrial CT scanner, which is devised to have 286 points of

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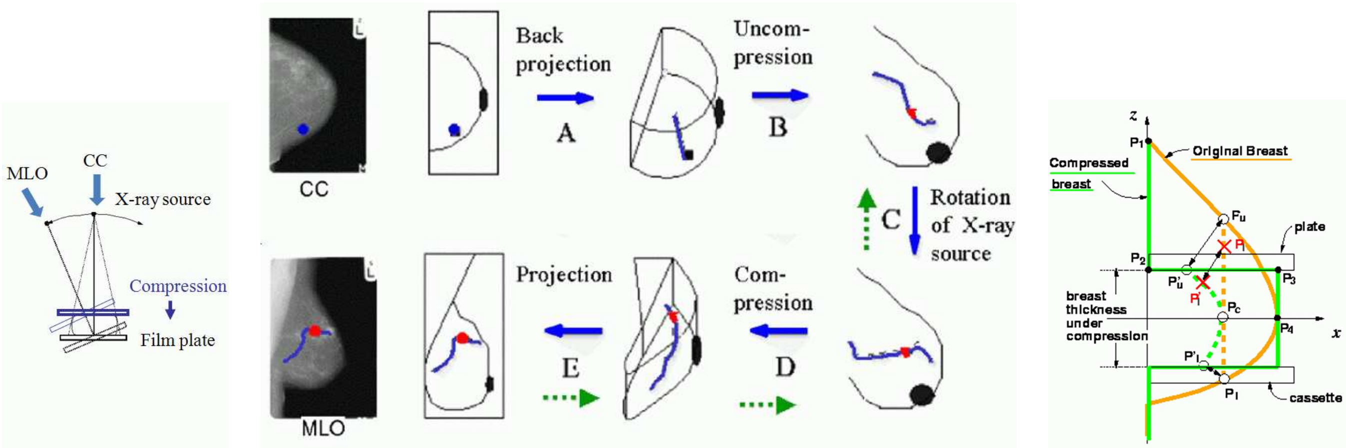



(a) (b) (c)

Fig. 1. Strategy for determining 3D position from two mammographic views.

marks inside of it. Finally, we discuss and clarify the matters to improve in Section V.

## II. Scheme of the CAD system [1]

Recently, performing two different views of the breast, the medio-lateral oblique (MLO) and cranio-caudal (CC), is spread in screening programs, since it may greatly improve sensitivity and specificity. When a mammogram is performed the breast is compressed between the film cassette and compression plate in the direction of the x-ray source: “head to toe” for the CC view and “over the shoulder diagonally to the hip” for the MLO view, as shown in Fig. 1(a). Unfortunately, radiologists find it difficult to relate points in the CC view to those in the MLO view because the breast is largely deformed in the different directions. To help their diagnosis, a CAD (Computer Aided Diagnosis) system which simulates the breast deformation during mammogram performance and suggests the corresponding position between different viewed mammograms has been developed[1]. The method calculates the epipolar curve, that is the locus of possible corresponding positions of the point in the other image by simulating the five steps of the process: A: back projection → B: uncompression → C: rotation → D: compression → E: projection as shown by the solid arrows as shown in Fig. 1(b). As a result, the line in the MLO image is calculated.

This physics-based approach have another merit: it also can help to estimate the 3D position of a lesion in the uncompressed breast, despite the fact that the breast is never imaged in the uncompressed state in mammography. This technique works after finding the corresponding point along the epipolar curve and then back-tracking the movement of the point during the simulation of the processes as shown by the dashed arrows in Fig. 1(b). Fig. 2 shows an example of the resultant 3D position obtained by the system. Here, the 3D shape of the individual breast shown in the right-hand two windows is automatically reconstructed from the breast outlines in CC and MLO images. This localization is very important to guide biopsies and/or fusion of multi-modal data

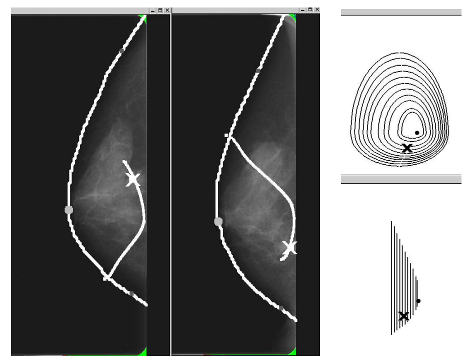


Fig. 2. 3D position of legion obtained by the CAD system

of the breast.

The breast deformation caused by compression and uncompression is simulated using the simplified geometrical compression model proposed in [16], This model enables the calculation of the position of any point of the breast under compression from its original position in the uncompressed state, and vice versa as shown in Fig. 1(c). The model was derived based on some approximations on the breast deformation under the compression as like:

**Approximation 1(A1)**. The cross-section for compression of the breast is deformed only in the plane by compression. Here, “the cross-section for compression” means the cross-section cut by the plane which is parallel to the compression direction and perpendicular to the chest wall.

**Approximation 2(A2)**. In the mid-plane between the plate and the cassette, there is no deformation.

Through experiments using about 50 pairs of CC and MLO images of both English and Japanese women [16][1], average error, which is distance from the actual corresponding point to the predicted curve, is less than 7 mm. It overcomes the current radiologists predictions, average error of which is about 10 mm. The accuracy can be improved by replacing

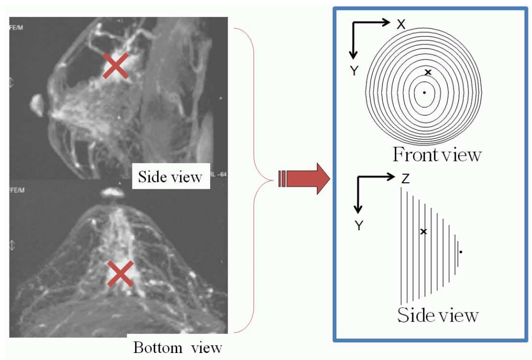



Fig. 3. 3D model reconstructed from MR MIP data

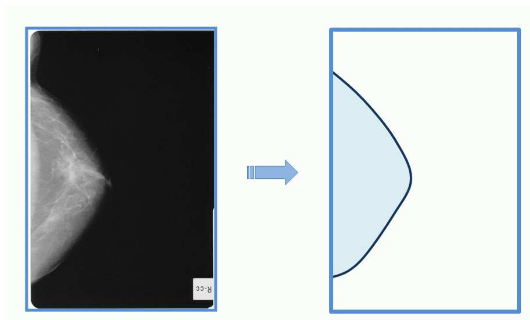


Fig. 4. CC data of the breast of the MR data in Fig.3

the compression model with a richer compression model, Actually, Zhang et al[13] uses a breast FEM model which is reconstructed from MRI data of the same breast to calculate the similar corresponding lines. The accuracy of the experimental results using six patients was reported as about 2.2 mm. However, it should be noticed the former method has merits of working only with the two view mammograms in real time, while the latter requires MRI of the same breast and takes much longer time. This characteristics is important for a handy and easy-to-use CAD system for aiding the diagnosis of mass screening with mammograms only.

Therefore, the improvement of the simplified compression model only with the input images is also desirable. Yam et al [17] improved the compression model by introducing some variable parameters into the model and by adjusting the values based on the correspondences of prominent features (micro-calcifications) on the images. However, mammographic views do not always have enough numbers of corresponding pairs of prominent features.

One direction is to build a more sophisticated geometrical compression model by understanding the breast deformation by compression in more details.

## III. Simulation of CC mammographic compression using a mechanical model

To understand better the breast deformation by compression, we simulated CC mammographic compression of breast using a mechanical model reconstructed from MR data and compared the results with actual CC image. We use the

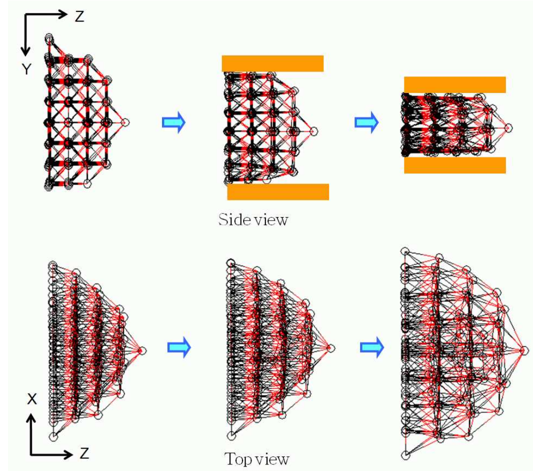



Fig. 5. Compression simulation 1

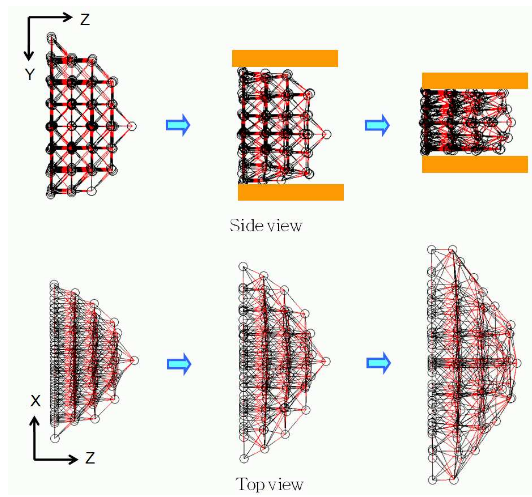



Fig. 6. Compression simulation 2

rheological model developed by Kimura et al.[18], which can simulate the deformation of elastic, viscoelastic. and plastic objects in almost real time. Although the parameters of this model are not directly related with actual biomechnical parameters like Young's modulus, these can be adjusted relatively intuitively. The 3D geometry of the model is reconstructed from outlines in MRI MIP (Maximum Intensity Projection) images as shown in Fig.3. For simulating compression by two plates, Dirichlet boundary conditions (displacement-controlled conditions) are applied to the nodes touched to the plates which move gradually towards each other until the distance between the plates becomes the width at taking the CC image. At the connection to the fixed chest wall, only the z coodinates of the nodes at the chest wall is fixed. Fig. 5 shows a top and side viewsof a simulation result. Although several simulations were tried while manually adjusting the parameters of the viscoelasticity of the model, the outline of the deformed breast did not get close to the one observed in the actual CC image in Fig. 4. The biggest difference is the tendency of elongation in the X

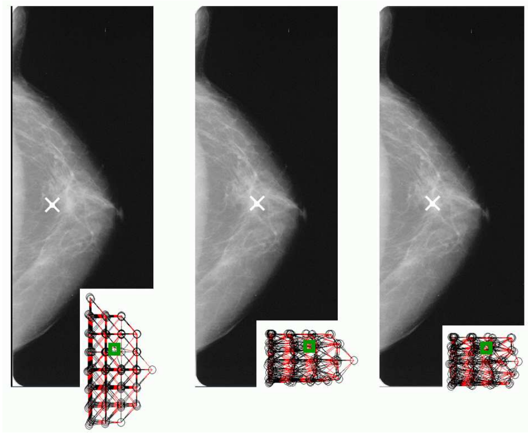


Fig. 7. Projected positions of a lesion detected in MR data

direction, which is perpendicular to the compression and along the chest wall. Although there are also some studies simulating the CC compression[10][13], the consistency of the simulated shape with the actual observation has not been sufficiently investigated. As far as we review, such tendency does not seen in any simulation results. We infer that this is mainly because both the connection with the chest wall and the compression action are fairly complicated and are not well implemented in the simulations. Actually, it is hard to represent this complicated boundary conditions. Instead of sticking to that, we add one more Dirichlet boundary conditions for the nodes on the horizontal plane through the nipple, so as to the outline of the shape after the simulation coincides with the one observed in actual CC image. Concretely, the nodes are forced to move to the position which produce the outline of CC. Fig. 6 shows the deformation of the breast using this condition.

To examine the effects of this modification on the internal deformation, we check the consistency of projected position of a lesion. In Fig. 7, white crosses illustrate three projections of a lesion which is detected in MRI (crosses in Fig. 3): from left to right, the projection of the location at original MRI shape, that after the compression simulation shown in Fig. 5 and that after the compression simulation shown in Fig. 6. As you see, the last one gives best coincidence. This result encourages us to make good use of the features observed in images to specify the deformation.

This observation also gives a clue to the improvement of the geometric compression model used in the CAD system: the modification realizing this tendency of elongation along the chest wall should be added.

## IV. Observation of internal deformation using devised phantom

In order to grasp internal deformation of flexible objects in details, Tokumoto et al.[19] has devised gel phantoms in which small metallic elements arranged with regular intervals and measured the movements of the elements using an industrial CT scanner, TOSCANER-24200AV. Fig.8 shows one example of the experimental results using a semi-ellipsoid phantom made of human-skin gel. The size of the phantom is 130 (major axis) $\times$ 110 (minor axis) $\times$ 70 (height) mm. 286 metallic elements are arranged inside of the phantom. To observe the internal deformation, the movement of the elements were observed by the CT scanner at three times: with no compression, under compression to the width of 100 mm, and under compression to the width of 80 mm. In Fig. 8(a), white, red and blue colors illustrate the position of the elements at each state respectively.

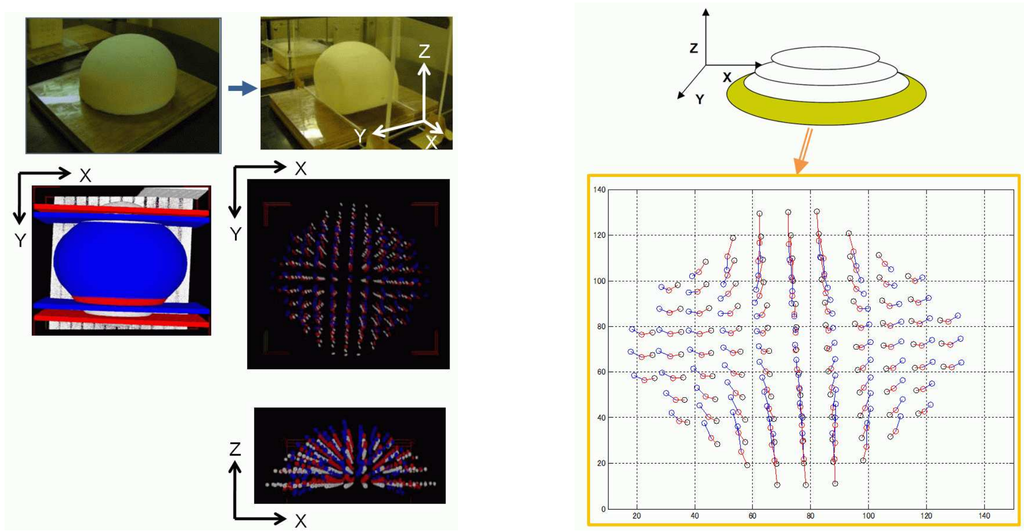
To observe more clearly, the movement of the metallic elements which on a horizontal plane at the initial state is picked up in Fig. 8(b). The movement in the compression direction (in the Y direction) is big at the part which are pressed directly by the plates (at the part of $X = 60 \sim 100$ in Fig.8(b)). On the other hand, at the remaining outer part, the movement in the X direction, which is perpendicular to the compression direction is stronger. One more noteworthy point is that the former part obviously got denser than the latter part under the compression. This gives us a valuable lesson that too strong volume conservation constraints could cause removal from reality.

This observation suggested some amendments to the compression model used in the CAD system.

1) On Approximation 1:
   In the current system, for simplification, we ignore the movement perpendicular to the cross-section and consider the deformation only within each cross-section. However, cross-sections tend to bend outward with the biggest displacement at the mid-plane between the plates.
2) On Approximation 2:
   In the mid-plane between the plates, deformation in the compression direction can by ignored. However, the displacements in the other directions should be considered.
3) On 3D reconstruction from the outlines of mammograms:
   In the current system, individual 3D breast shape is reconstructed on the assumption that its horizontal and vertical outlines can be approximated with 10-percent scale-downed outlines of CC and MLO images respectively[1]. However, it looks better to take into consideration the distortion of the outlines during the compression rather than assuming the change as similar transformation.

## V. Conclusions

In this paper, we discussed about the model which can simulates breast compression for practical medical applications. To shed light upon the physical deformation of breast under mammographic compression, we have done two-types of experiments: simulation of mammographic compression using a mechanical model and inspection of internal deformation using a devised phantom. Based on the experimental results, Some key issues to improve the compression model used currently in the CAD system[1] were specified in Section IV.




(a) (b)

Fig. 8. Inspection results of internal deformation of a phantom with metallic elements inside

Our future work will focus on:

1. Further investigation of the breast deformation under mammographic compression by increasing the number of the experiments in-line with ones shown in this paper.

2. Development of more sophisticated compression model for the CAD system based on the facts obtained from the experiments above.

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