A CAD system for 3D locating of lesions in mammogram

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Abstract. A CAD system for estimating the 3D (three dimensional) positions of lesions found in two mammographic views is described. The system is an extension of our previous method which finds corresponding 2D positions in different mammographic views by simulating breast compression [1] . In this paper, we first explain the principles and process flow of the system. The correctness of the 3D position calculated by the system is examined using breast lesions, which are found both in mammograms and in MRI data. Results from experiments show that the CAD system has clinical promise.

1 Introduction

Mammography (breast x-ray) is currently by far the best trade-off between specificity/sensitivity and cost to detect breast cancer in its early stages. As a result, screening programmes have been established in a number of countries, including the UK, Netherlands, Sweden, and Australia. Currently, screening programmes are being established in France, Germany, and Japan. There has been a considerable amount of previous work on CAD (Computer-Aided Diagnosis) systems for mammograms[2]. Most aim to detect lesions (including tumours) in images. Hardly any yield 3D (three dimensional) information, for example the 3D position and volume of lesions, which is important information for the ensuing diagnosis and treatment.

Obtaining 3D information about breast lesions from mammograms has not been accorded a great deal of attention, because breast compression (primarily to reduce x-ray dosage), which almost always varies markedly between the cranio-caudal (CC) and mediolateral oblique (MLO) views, involves a complicated relationship between the 2D positions of a point in the two images and its actual 3D position in the uncompressed breast. Although other modalities, most notably MRI, nuclear medicine and ultrasound, can be used to get the required 3D information, some of the most important early indicators of cancer, e.g. calcifications, can only be observed in mammograms. It turns out that the 3D distribution of such early signs is clinically significant [3][4]. Nevertheless, few clinical studies consider how a lesion appears in an x-ray image based on the projective principle[5],[6].

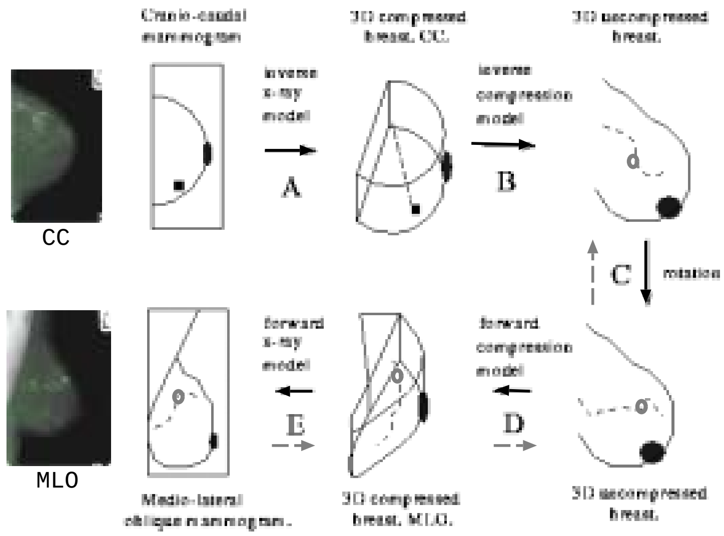


Fig. 1. Strategy for determining 3D position from two mammographic views.

It has recently been proposed that acquiring two views of the breast, medio-lateral oblique (MLO) and cranio-caudal (CC), greatly improves sensitivity and specificity. If a lesion is seen in both images, then, theoretically at least, its 3D position should be determined based on the principles of stereo vision. However, as we noted above, the breast compression in the CC and MLO differ quite markedly. As a result, the epipolar geometry, that is the determination of the straight line in one of the images that corresponds (ie the locus of candidate matches) to a point in the other image is deformed into a curve. Hence, the correspondence problem for lesions is not at all intuitive and becomes a difficult task. Kita, Highnam and Brady[1] proposed the first method to estimate curved epipolar lines by developing a simulation of breast deformation into stereo camera geometry. Using such curved epipolar lines, we can not only determine correspondences, but can estimate the 3D location of a lesion within the uncompressed breast. Using this information together with a quantitative measure obtained from calibrated image brightness, Yam et al. [3] showed how to match each microcalcification in the cluster between the two views and reconstructs the cluster in 3D. However, the correctness and accuracy of the 3D location obtained from the epipolar curves has not to date been investigated thoroughly.

The 3D position of a lesion in a mammogram, provided by our method, presents the radiologist with new, clinically significant, information that enables her/him to diagnose and treat cancer earlier and less invasively. For this reason, we have built a pilot CAD system based on the method. In this paper, we describe the system and analyze the error in the 3D locations of lesions. In the following section, we first explain the principles and process flow of the system. The results offered by the system is examined using the breast lesions which are

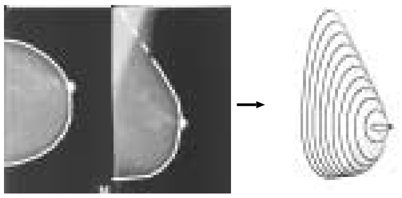
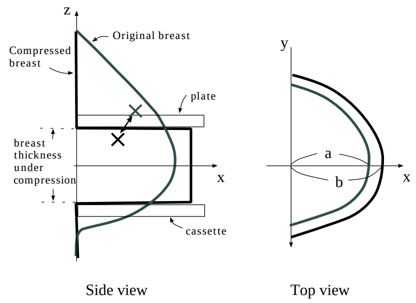


Fig. 2. 3D reconstruction of the breast



(a) (b)

Fig. 3. Schematic breast compression

found both in mammograms and in MR images. Finally, we discuss the current capabilities of this system at the present and what problems should be solved in the future.

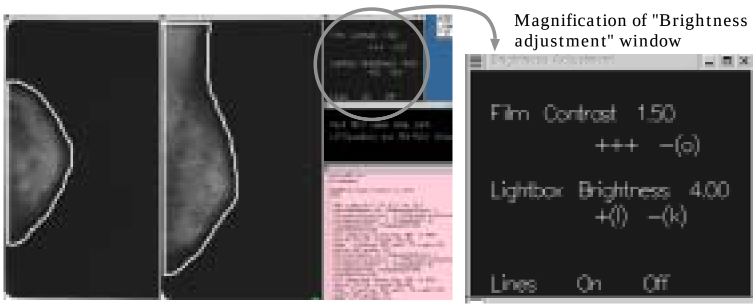
2 CAD system for 3D locating of lesions in mammogram

2.1 Principle

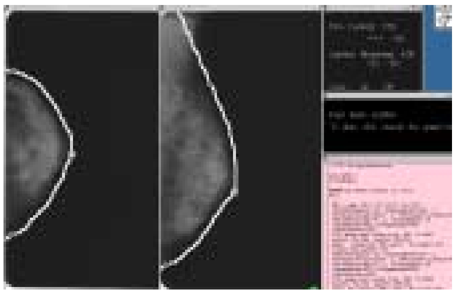
When a mammogram is performed, the breast is compressed between the film-screen cassette and compression plate in the direction of the x-ray source: "head to toe" for the CC view and "over the shoulder diagonally to the hip" for the MLO view. Figure 1 shows an overview of the system. Further detail is given in [1]. First, suppose that a point in one image is pointed at by a radiologist. 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 $\rightarrow$ B: uncompression $\rightarrow$ C: rotation $\rightarrow$ D: compression $\rightarrow$ E: projection as shown by the solid arrows. Next, the corresponding position is searched for along the epipolar curve. Once the correspondence is found along the curve, the corresponding 3D position in the uncompressed breast can be determined by back-tracking the movement of the point during the simulation as shown with the dashed arrows.

We define the canonical shape of the uncompressed breast as follows. According to established guidelines for taking mammograms [5], the breast is pulled gently away from the chest wall before compression so that all tissues can be seen without any folding. We define the breast shape when it satisfies this condition as the canonical shape, since it is close to the intrinsic shape of the breast without the effect of gravity. From the observation that the outlines of CC and MLO images are, respectively, close in shape to the horizontal and vertical contours of the breast in this canonical state, the canonical shape can be reconstructed automatically from the outlines, as shown in Fig. 2.

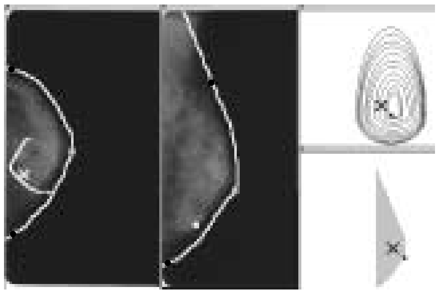
The simulation of breast deformation caused by compression and uncompression is realized by the model proposed in [1], which calculates the position of any point of the breast under compression from its original position in the canonical state, and vice versa, as shown in Fig. 3a. Although in the previous paper [1], the distance from the nipple to the chest wall was assumed to be fixed during



(a) Initial display



(b) Display at the middle of operations



(c) Resultant display

Fig. 4. Interface of the proposed system

the compression, we observed that in practice the change in the distance caused by compression can be significant. Therefore, we have improved the compression model so that it can take account of the expansion of the horizontal cross section. The expansion rate, which is b/a in Fig. 3b, depends on the individual and the strength of compression. In comparison with the 3D breast shape of the corresponding MRI data, we currently select 1.1 as the average rate and use this value for all the experiments in this paper.

2.2 Operation

The data necessary as inputs to the system are the CC and MLO images of the same breast, as well as the angular separation between the CC and MLO directions, and the thicknesses of the compressed breast in the CC and MLO directions. Figure 4a shows the screen at the start. The left two windows show CC and MLO images respectively. Their brightness and contrast can be changed by clicking "+" and "-" in the "Brightness adjustment" window on the upper right. Beneath this window, the user can always see what to do next in the "Messages" window. White lines in the images are the outlines of possible breast regions which are automatically extracted[7].

The operation required of the radiologist is as follows:

1) To click edge points of breast outlines and the nipple positions.

Since not all parts of the breast outline are observed on the images, mainly because of overlap by the pectoral muscle, the radiologist needs to select the part which shows actual breast outline. The missing parts of the outlines are extrapolated by simple extension from the tangent to the adjoining part of the observed outline. As a result, the breast outlines are fixed as shown by the white lines in Fig.4b. The six gray points on the lines are points clicked by the radiologist. The 3D canonical shape of the breast is reconstructed from these two lines.

2) To click the position of a lesion in any of CC/MLO images.

Fig.4c shows an example in which the position illustrated by the white point in the MLO image was clicked. Within a second, the epipolar curve is displayed as shown in the white line in the CC image.

3) To click the position of the same lesion in the other image.

The radiologist can search the neighborhood of the line for the corresponding point. In the example shown in Fig. 4c, the position illustrated by the white cross was clicked. In one second, the estimated 3D position of the lesion is displayed in the right-hand two windows and marked with crosses in the top and side views of the 3D canonical shape.

If there is more than one lesion in the images, as is quite often the case, the radiologist can successively input the next lesion and can repeat steps 2) and 3). Although we show the images here in black-and-white, the windows are actually displayed using color marks.

3 Experiment

In general, it is difficult even for radiologists to determine accurate correspondences between the CC and MLO images. However, radiologists can determine some correspondences with confidence, based largely on the similarity of the intensity patterns in the two images. We have gathered five lesions for which correspondences between the CC and MLO images were known, and in such a way that the lesion is also observed in MRI data. We then applied our method to the lesions.

Regarding the prediction of the correspondence in the other image, the minimum distances from the correct position to the resultant epipolar curve are measured and listed in Table 1. The second column, CC$\rightarrow$MLO is the case where the radiologist inputs the lesion in the CC image first, and then the system predicts the position in the MLO image, and vice versa for MLO$\rightarrow$CC in the third column. As shown in the table, apart from case 5, the system gives good predictions which are less than 7.5 mm (25 pixels).

Fig. 5a and b show the best (No.2 in Table 1 & 2)and the worst (No.5) results respectively. The left-hand figures show the results obtained by the proposed system, while the right-hand ones are the side and top MIP (Maximum Intensity Projection) images obtained from MR images and the 3D breast shape reconstructed from the outlines in the MIP images. Since the MR images are taken with the breast pendulous while the subject lies on her front, the 3D breast shape from MRI data is elongated by gravity in the direction from the chest wall to the nipple, that is, in the x direction in the 3D coordinates of the system (see Fig. 3). Therefore, the canonical shape of the system should be close to a suitably reduced shape of the 3D breast in the MRI in the x direction. From this stand

Table 1 Minimum distance between the correct position and the resultant epipolar curve measured in pixels (0.3mm) in 600 × 800 images.

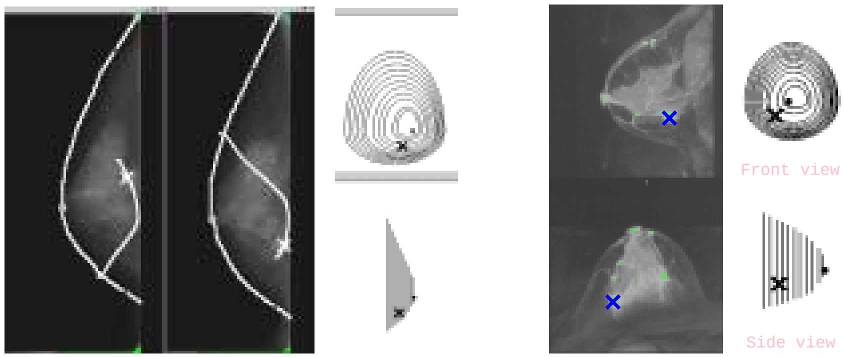
No.	CC→MLO	MLO→CC
1	24.3	2.0
2	2.4	0.6
3	22.5	18.3
4	2.1	1.8
5	80.0	37.5

Table 2 Relative 3D position of lesions to the nipple: Euclidean distance(x, y, z)(mm)(refer the 3D coordinates in Fig. 3)

No.	A: CC→MLO	B: MLO→CC	C: MRI	C-(A+B)/2
1	39.3(-5.6, -14.8, 36.0)	38.2(-9.3, -14.1, 34.3)	43.0(-37.5, -3.7, 20.7)	4.3(-30.1, 10.8, -14.4)
2	44.3(-27.3, 18.6, -29.5)	43.5(-27.8, 18.2, -28.1)	55.7(-51.3, 15.0, -15.5)	11.8(-23.8, -3.4, 13.3)
3	31.6(-26.9, 12.2, 11.1)	27.1(-24.0, 9.5, 8.3)	33.6(-31.7, 10.4, -4.2)	4.2(-6.3, -0.45, -13.9)
4	71.6(-51.7, 40.9, 27.9)	67.5(-44.1, 42.2, 28.9)	73.6(-72.4, 6.5, -11.8)	4.0(-24.5, -35.1, -40.2)
5	68.2(-16.6, 34.5, 56.2)	88.8(-29.5, 34.0, 76.5)	73.3 (-59.7, 23.0, 35.7)	-5.2(-36.7, -11.3, -30.7)

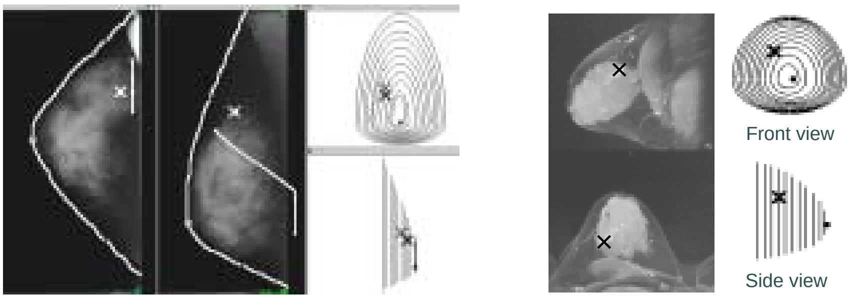
point, in case No.5, the nipple position in the 3D breast reconstructed from the mammogram looks unnaturally low as the canonical shape. The reason why this occured seems to be that the breast was not pulled away sufficiently from the chest wall before compression for the MLO image and was compressed under the condition that the breast is elongated downward (the negative z direction of the 3D coordinates) by gravity. We infer that this causes the epipolar curve to be transformed downwards from the actual corresponding position in the MLO image. If the guideline for taking mammograms was adhered to properly when taking the MLO image, the nipple position could be further up while the outline is not so different from the current state. We simulated this case by intentionally giving a higher position for the nipple on the MLO outline as shown in Fig.6. As one can see, the epipolar curve gets closer to the actual correspondence.

The 3D positions of lesions found in the MR images are marked by a cross in both the MIP images and in the reconstructed 3D shape. Table 2 shows the distances and relative positions of lesions to the nipple. The second, third and fourth columns are respectively the results obtained by the system with the first input in the CC image and the second input of the corresponding position in the MLO image, the results obtained by the system with the inputs in the reverse order, and the values obtained from the MRI data. The fifth column shows the difference between the MRI result and the average of the results by the proposed system. On No.1, No.2 and No.3, the differences are under 15 mm apart from the values of the x coordinates. One reason for the large difference in the x coordinates is because the breast is elongated in the x direction in the MRI data as noted above. Concerning cases No.4 and No5, their breasts are relatively large so that their breasts have a “hanging bell” shape in the MRI data. The distance of the nipple from the chest wall changes from about 75mm in their canonical shape to about 90 mm in the 3D shape of the MRI data. These observations show that the deformation from the canonical shape assumed for the breast



Results obtained by the proposed system Position in MRI data

(a) No.2 in Table 1 & 2



Results obtained by the proposed system Position in MRI data

(b) No.5 in Table 1 & 2

Fig. 5. Experimental results

shape in the MRI data is too large to be ignored in these cases. Therefore, in these two cases, comparison of the 3D coordinates appears nonsensical. This is supported by the fact that the difference in Euclidean distances, which should not be changed much by the effect of the deformation, is fairly small, less than about 10mm, for all five data sets. From these observations, we conclude that the proposed system can estimate the 3D position in the canonical shape to about 10 mm error.

4 Conclusion

In this paper, we have described a developing CAD system for estimating the 3D positions of breast lesions found in two mammographic views. This is the first demonstration of a CAD system which enables the radiologist to obtain 3D information from a conventional pair of CC-MLO mammograms. Since some lesions are observed only in mammograms, this has considerable clinical significance.

From the experimental results, particularly the comparison with the 3D information provided by MRI data, the following two conclusions emerge. First, it is a necessary condition for applying this system that the breast is pulled gently away from the chest wall before the compression necessary for mammography, that is, in accordance with the established guidelines for taking mammograms.

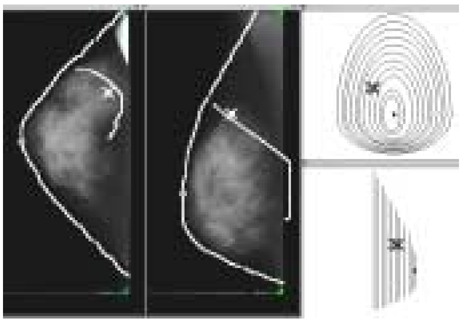


Fig. 6. Effect of the movement of the nipple

Since the effects of gravity on the soft, and sometimes heavy, breat tissue tends to prevent radiographers from adhering strictly to this condition, careful mammogram image formation is required, especially for MLO images. Second, we have concluded tentatively that the system achieves about 10mm errors in estimating the 3D locations of lesions. In order to assert this with greater certainty, however, we need more understanding of the breast deformation between the breast shape during MR image formation and its relationship to the canonical shape used in the system. This study is also important for the fusion of multi-modal data of the breast.

Acknowledgements

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