Detection of Linear Structures in 3D Breast Tomosynthesis Images

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Abstract. Two–dimensional projection mammography has several inherent limitations caused by the projection of the 3D breast anatomy on to a 2D plane. These limitations are known to result in false–negative or false–positive diagnoses. Three–dimensional tomosynthesis imaging has the potential to alleviate or eliminate these limitations. Breast density is an important indicator of mammographic risk, however it has been suggested that the density and/or distribution of linear structures may be linked to risk. Recent studies have correlated linear density in two–dimensional mammograms with risk, and this preliminary study demonstrates that linear structure information can be automatically detected from three–dimensional tomosynthesis image volumes and correlates with linear density detected in mammograms.

The study analyses digital mammograms and tomosynthesis images taken from 39 women. Mammogram and tomosynthesis acquisition were performed on the same day. Both sets of images were analysed using a line detection algorithm and the above–threshold linearity of corresponding mammograms and tomosynthesis images compared. Results showed a good degree of correlation (Pearson's coefficient 0.73) between the linearity detected in corresponding images, suggesting that detected linearity in tomosynthesis images may be correlated with risk.

Future work intends to investigate this link further, as it is hypothesised that information available in tomosynthesis images may eventually provide a better indicator for risk that that available in two–dimensional mammograms, due to the inherent advantages of the three-dimensional images.

1 Background

1.1 Tomosynthesis

Conventional two-dimensional projection mammography plays a very significant role in breast cancer detection, diagnosis and treatment. However, it is well–known that 2D mammography has several inherent limitations, caused by the projection of the 3D breast anatomy on to a 2D plane. These include cancers being obscured by superimposed normal tissue and overlapping normal tissue creating the artificial appearance of densities [1, 2]. These limitations often result in false–negative or false–positive diagnoses, increasing risk to the patient or exposing them to unnecessary anxiety and often painful follow–up procedures.

Whereas many of these limitations could be overcome by magnetic resonance imaging (MRI), this is a far more involved procedure and its high cost, inconvenience and low availability prevent the use of MRI from becoming widespread for the detection of breast cancer.

Three–dimensional breast tomosynthesis provides a significant advance over projection mammography. Tomosynthesis effectively eliminates the effects of superimposed tissue on parenchymal structures of interest [2–4]. This can increase margin visibility, especially in dense breasts and has been shown to improve lesion visibility [5].

Breast tomosynthesis acquires a series of projection x–ray images as the x–ray source moves in an arc around the fixed breast and digital imaging detector. With the exception of their acquisition angle, the 'raw' projection images are similar to conventional x–ray mammograms, however they are taken using a significantly lower x–ray dose than that using for conventional mammograms, such that the overall dose received by the patient is similar for the two methods [2, 5].

The raw projection images are subsequently reconstructed in to a three–dimensional volume that can be displayed to a radiologist. Many algorithms have been used in the reconstruction of tomosynthesis images, common examples include filtered back projection and shift–and–add.

1.2 Risk & Linear Structures

Mammographic risk assessment is concerned with estimating the probability of women developing breast cancer. Risk assessment can provide an indication of when to recommend more frequent screening, which has been shown to

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improve the likelihood of the early detection of breast cancer [6]. Breast density is an important indicator of mammographic risk [7, 8] and the best predictor of mammographic sensitivity [9].

However, it has been suggested that the distribution of linear structures is also correlated with mammographic risk [10, 11]. So far it is not entirely clear if it is just the density of linear structures (either by percentage area or volume) or if the distribution of the linear structures plays a role as well.

Recent work has demonstrated that the density of linear structures in two–dimensional mammograms can be automatically correlated with mammographic risk [12]. Due to the potential advantages of three–dimensional breast tomosynthesis, is is suggested that the parenchymal pattern visible in tomosynthesis volumes may provide a better indicator of mammographic risk than that visible in two–dimensional mammograms [13].

2   Data

Digital mammograms and digital tomosynthesis images were acquired from 39 women during a clinical trial. Mammogram and tomosynthesis acquisition were performed on the same day using a GE Senographe 2000D FFDM system. The system was modified to allow a series of nine projection tomosynthesis images to be taken across a -25° − +25° range at 6.25° intervals. Projection images were acquired with a pixel resolution of 0.1mm.

Filtered-backprojection was used to reconstruct three-dimensional tomosynthesis volumes, with slices at 1mm intervals and an in–plane pixel resolution of 0.22mm.

Figure 1 shows a typical mammogram and slices from a corresponding tomosynthesis volume.
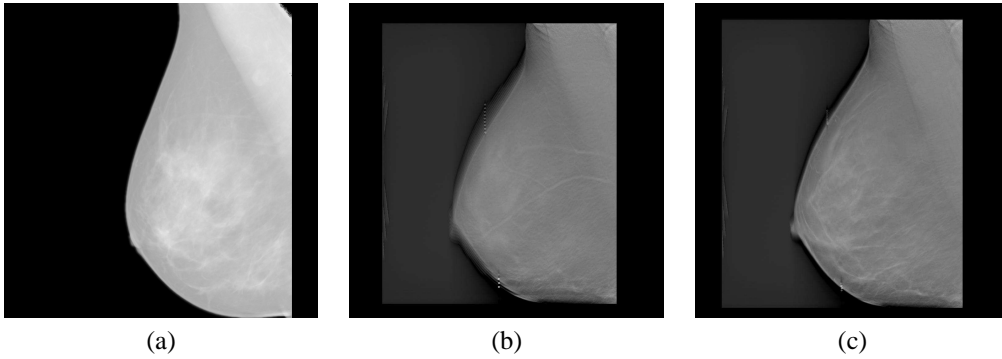

| (a) | (b) | (c) |

Figure 1. A typical mammogram (a) and two slices from the corresponding tomosynthesis volume (b–c). The first slice (b) is from close to the edge of the volume and shows the skin layer, whereas the second slice (c) is from close to the centre of the volume and shows the deeper fibro-glandular tissue.

3   Method

The two–dimensional mammograms and three–dimensional tomosynthesis volumes were processed using linear structure detection algorithms. The method of line detection used on 2D mammograms is an implementation of Dixon and Taylor's line operator [14], shown to be more accurate than other methods [15].

The method calculates a measure of line strength and orientation for each pixel in an image as follows:

For each pixel, a line strength measure (S) is calculated by applying

$$S = (L - N) \tag{1}$$

in multiple orientations, where L is the mean grey–level value of a line of pixels of length 5 centered on the target pixel, and N is the mean grey–level value of a similarly–orientated square of pixels. For each pixel, the maximum S is selected and its corresponding orientation taken to be the pixel's line orientation. In this study, the line strength was measured at 12 equally–spaced orientations.

This method was adapted for use on the three-dimensional tomosynthesis images by calculating the mean grey–level of a line of voxels at a range of orientations in both axes, and subtracting the mean grey–level of a similarly–orientated

cube of voxels. Prior to processing, each slice was scaled to produce a pixel resolution approximately equal to the between–slice resolution.

A multi-scale approach was used in order to detect lines of a range of thicknesses, whereby the images were blurred using a 3x3 Gaussian filter then subsampled to produce an image at half the width and height of the original. The line detector was applied independently on the images at each scale and then combined by taking the maximum line strength value from the corresponding pixel(s) in each scaled image. Three scales were used with the 2D mammograms and two scales with the tomosynthesis images, since the original images were smaller than the original mammograms.

Finally, the pixel line strengths were thresholded to remove background texture and artefacts. A measure of above–threshold linearity was calculated for each image as an indicator of linear density. Areas outside of the breast area were masked and discarded.

Linearity measures for corresponding 2D and 3D images for each patient were compared.

4 Results

Figure 2 shows line detection results for a typical two–dimensional mammogram. The figure shows the original digital projection mammogram alongside the unthresholded and thresholded line detection result images.
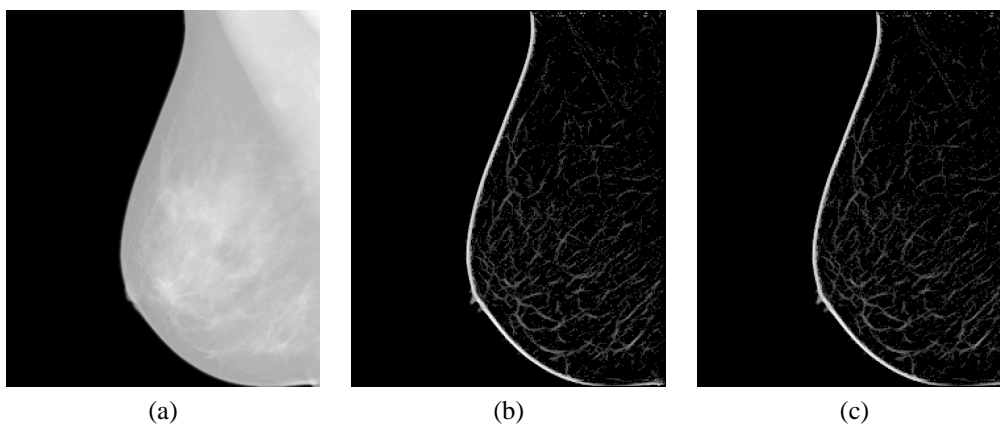

(a)   (b)   (c)

Figure 2. Mammogram line detection results. Original mammogram (a) alongside the unthresholded line detection results (b) and thresholded line detection results (c).

Typical line detection results for the three–dimensional tomosynthesis images are shown in Fig. 3. This figure shows sample results for a series of slices in 5 slice increments. For each slice, the original slice image is displayed alongside both the unthresholded and thresholded line detection result images. The initial output images are thresholded at a level most suitable for removing background and reconstruction artefact noise whilst maintaining the linear structure information.

Figure 4 shows a graph of the detected linearity in two–dimensional mammograms against the detected linearity each corresponding three–dimensional tomosynthesis image. The results demonstrate a good degree of correlation (Pearson's coefficient 0.73).

5 Discussion

The comparison between the linearity detected in two–dimensional mammograms and corresponding three–dimensional tomosynthesis images shows a good degree of correlation, achieving a correlation coefficient of 0.73. Since the linearity in two–dimensional mammograms has been well–correlated to mammographic risk [12, 16], it can be expected that the linearity in tomosynthesis images may also be correlated to risk.

This study is limited in several aspects by the lack of availability of a wide range of image data. Currently, breast tomosynthesis is experimental and only a handful of tomosynthesis machines currently exist, and as such most of the images taken are of patients with known cancers during clinical trials [2]. The small dataset used (39 images) is clearly a limitation of this study, however it is not currently clear how this can be overcome.
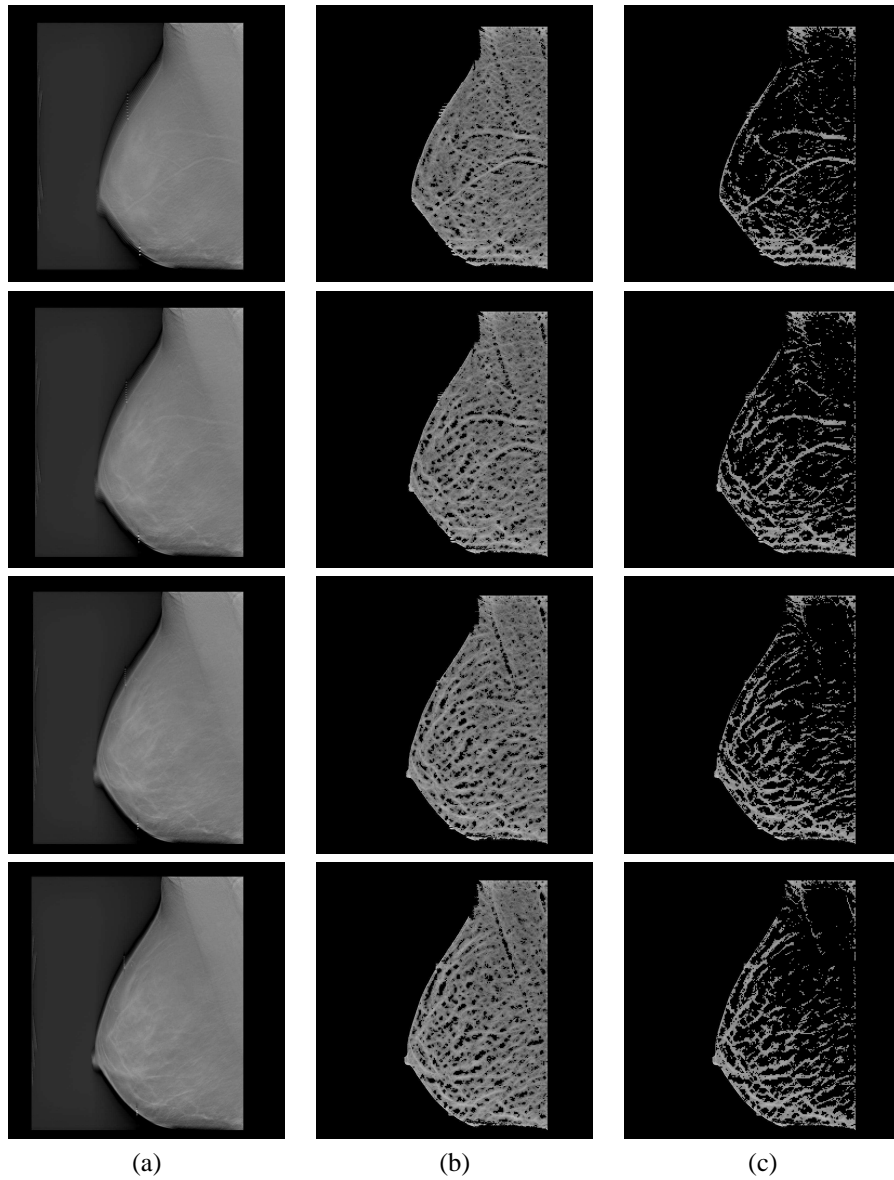
| (a) | (b) | (c) |

Figure 3. Tomosynthesis line detection results. Each row shows an image slice with an interval of 5 slices between rows. The top row shows a slice close to the edge of the volume, whilst the bottom row shows a slice close to the centre of the volume. In each row, column (a) shows the original tomosynthesis slice, column (b) shows the unthresholded line detection results and column (c) shows the thresholded line detection results.
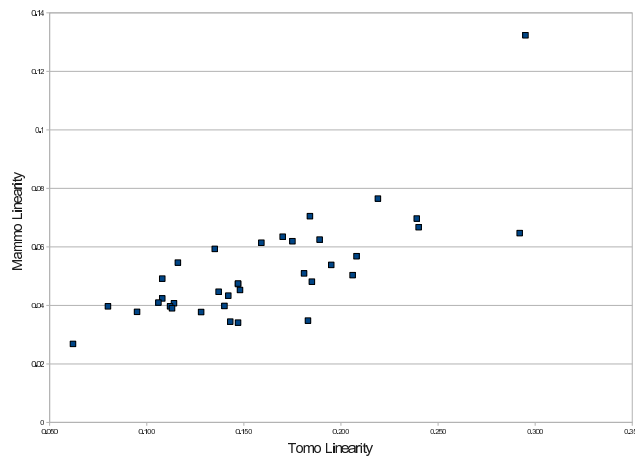

Figure 4. A comparison of the linearity of two–dimensional mammograms and corresponding three–dimensional tomosynthesis images.

A direct comparison between three–dimensional linearity and mammographic risk would be a ideal continuation, however this would be almost impossible in practice due to the limited data available. Such a comparison would require a large dataset of tomosynthesis images that are spread across all risk categories, whereas currently–available datasets are generally small and images are concentrated around the high risk categories, making any valid statistical comparison unlikely.

Other recent studies have suggested a link between the parenchymal pattern visible in tomosynthesis images and mammographic risk [13]. It was also suggested that, due to the advantages of three–dimensional images in mammography, the parenchymal patterns visible in three–dimensional tomosynthesis images might eventually be expected to provide a better indicator of risk than those currently available from two–dimensional mammograms [13].

Therefore, a perfect correlation result in this experiment would not be ideal, as it would indicate that there is no additional information available in the three–dimensional tomosynthesis images.

Future work is intended to further investigate the link between the pattern of linear structures in three–dimensional tomosynthesis images and mammographic risk, including the possibility of matching detected linearity against Tábar's expected measures of linear density [11].

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