Compressed Breast Shape Characterization and Modelling During Digital Breast Tomosynthesis using 3D Stereoscopic Surface Cameras

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ABSTRACT

Some image processing techniques for digital mammography (DM) and digital breast tomosynthesis (DBT) require or assume prior knowledge of the three-dimensional (3D) shape of the compressed breast. Our goal is to characterize the breast shape curvature during mechanical compression for DM and DBT acquisition, and to study its dependencies on relevant patient features to improve this prior knowledge. For this, patients were recruited to undergo 3D breast surface scanning during breast compression for their clinical DBT examination. This surface scanning system included two sets of a digital projector with a pair of stereoscopic structured light cameras, each positioned at each side of the DBT system. Features from the patients were extracted from the DBT images while the 3D surfaces were used as input to a previously developed principal component analysis (PCA) breast shape model. From the cases included in this study, 70 scans with full breast coverage and without artefacts were selected for this interim analysis. The enhanced coverage with the stereoscopic setup resulted in improved characterization of the breast shape curvature, yielding an asymmetry in the curvature between medial and lateral side. Linear correlation between the first PCA component and the thickness of the breast was found, but not for the other components. A multiple regression analysis was applied, finding no significant correlation between curve shape and patient characteristics. Searching for other factors that could be used to predict the breast shape when compressed, and testing for non-linear correlations will be addressed as a next step.

Keywords: breast compression, principal component analysis, structured light scanning

1. Introduction

Due to the use of mechanical compression of the breast during digital mammography (DM) and digital breast tomosynthesis (DBT), many state-of-the art image processing algorithms involve the simulation of the breast undergoing compression.[1,2,3,4,5,6] Recently, work by Rodriguez-Ruiz et al.[7] managed to characterize and model the 3D compressed breast shape, involving the tissue curvature between the detector cover and the compression paddle, for DM and DBT. This was achieved by imaging patients' breast surface with state-of-the-art structured light (SL) technology while the patient underwent a normal cranio-caudal (CC) view DBT image acquisition. However, that initial proof-of-concept work was limited in the number of patients included in the study, and was performed on a single tomosynthesis system from a single manufacturer. This made it difficult to generalize the results obtained, and the poor image coverage for thicker breasts due to hardware resources did not allow for a good angular coverage, resulting in a limited characterized thickness range.

Here we present interim results of a larger study on the compressed breast shape during DBT, by examining a new and larger study population, with a system from a different vendor, and by improving the 3D SL scan acquisition setup and workflow. The goal is to use this new data to evaluate how different patient characteristics can influence the modelling of the breast shape curvature when the breast is compressed for a DM and DBT CC view acquisition.

2. Method

A dataset of tomosynthesis images combined with 3D SL scans of the breast was collected. Then, the 3D SL scans were post-processed and evaluated using principal component analysis (PCA). Relevant parameters from the patients were extracted from the DICOM header in the DBT images. Finally, we studied possible correlations between each PCA component and patient features.

2.1 Image acquisition and post-processing

Patients with a medical history of breast cancer undergoing a DBT exam at Radboud University Medical Center, Nijmegen, the Netherlands, were invited to participate in this study. To obtain the 3D breast shapes, two sets of SL scanning systems (HP Inc., Palo Alto, CA, USA) were positioned on each side of a clinical DBT system (SIEMENS Mammomat Inspiration, Erlangen, Germany) as previously described[7]. In this study, each set consisted of two cameras per projector,

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working in stereoscopic mode, achieving an increased angular coverage of the breast, even for thicker breasts. The SL systems were set to the left and right sides of the DBT system. Since this technology works with visible light, no additional radiation dose is involved and no laser light is used, thus requiring no eye protection. To ensure a good alignment between left and right scans, markers were placed on the sides of the compression paddle. The total SL scan time, which partially takes place during the 25s DBT acquisition, is approximately 15s.

Once the SL scans are finished, the software (HP 3D scan V5, HP Inc., Palo Alto, CA, USA) processes the information recorded by the cameras to obtain a 3D representation of the surface of the scanned object. Afterwards, appropriate cleaning by removal of spurious non-breast surfaces and fusion of the 3D SL scans was carried out in MeshLab (Visual Computing Lab, ISTI - CNR, Pisa, Italy), as can be seen in figure 1, while the 3D characterization of the compressed breast surface between the support and the compression paddle was performed following the procedure described previously[7] . As before, the breast surface was divided into 13 different equiangular-spaced arcs placed every 15° along the breast perimeter (from -90° to 90°) to simplify its characterization and modelling.

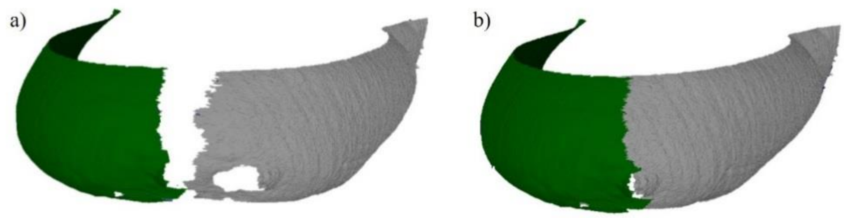

Figure 1 - Example of a cleaned scan (a) before and (b) after merging in MeshLab.

2.2 PCA of the breast surface arcs and data analysis

A PCA of the arcs was performed in Matlab 2018b (MathWorks, Natick, MA, USA) using 13 arcs from each breast, following a model which assumes a varying curvature along the surface[7]. In this manner, a smaller set of independent parameters comprising most of the information in the data points[8] can be obtained from the set of arcs. Each arc was resampled to a set of 20 equidistant points along the curvature in order to ensure that the same number of points per arc was used for the PCA.

When this analysis was completed, histograms of the PCA model parameter values of all studied breasts were created. Then, a Gaussian function (mean μ, standard deviation σ) was fit to these histograms to enable new PCA parameter values following that distribution to be obtained. The next step was to evaluate the influence of each PCA parameter on the shape of the arcs by varying its value independently, from $(\mu - 2\sigma)$ to $(\mu + 2\sigma)$, while the remaining parameters were held constant at their mean. Further information on the procedure can be found in our previous work [7,9,10].

Because our interest was to study how different patient characteristics can influence the modelling of the breast shape curvature under compression, patient features were also extracted from the DBT images acquired concurrently with the 3D SL scans. Features such as chest-to-nipple distance, glandular volume, glandular percentage, total breast volume, age, compressed breast thickness, and compression force were either available from the exam DICOM header or determined using Volpara ™ (v1.5, Matakina Technology Ltd., Wellington, New Zealand).

Hereafter, the ability to describe each PCA component through the use of patient features was evaluated. First, 6 PCA components (found to represent 90% of the cumulative variance encountered in the breast contour) were used to evaluate possible linear relationships with each individual patient feature. Then, a multiple regression was tested to evaluate if pairs of features together could better characterize the variation found in each PCA parameter.

3. Results and Discussion

A total of 70 cases with full breast coverage and no 3D SL scanning artefacts were selected for this interim analysis. In table 1, an overview of the study population characteristics can be found. It should also be noted that an equal sample of left and right breasts was used, which helps to take into account deformations on the breast shape under compression regardless of the side that was evaluated. To get consistent medial/lateral directions, the left side breast images were mirrored.

Table 1 - Characteristics of the patients and the imaged breasts.

Patient Features	Mean (Std. Dev.)
Age (y)	62 (10)
Imaged Breast Laterality	Left = 35; Right = 35
Compression Force (N)	83 (23)
Thickness (mm)	63 (11)
Chest-to-Nipple Distance (mm)	102 (23)
Total Breast Volume (cm^3)	892 (427)
Glandular Volume (cm^3)	52 (25)
Glandular Percentage (%)	14 (9)

The mean arcs found by the PCA model are displayed in figure 2, where the differences between the medial side (from 0° to 75° cuts) and the lateral side (from -75° to 0°) can be seen. These findings differ from the previous publication[7] where medial and lateral side showed a similar curvature. Here we see that the lateral side arcs have a sharper curvature compared to the medial arcs. Potentially, the lateral side of the breast is composed of more loose tissue, which could explain why its shape is deformed to a larger degree compared to the tissue on the medial side. Additionally, the scans were performed with an additional camera on each side of the DBT system, which lead to a better coverage of the breast, both close to the nipple (0° angle cut) and at its angular extremes (-75° and 75°). On the other hand, the results from the evaluation of the influence of each PCA parameter on the shape of the arcs by varying its value independently, showed comparable results to the previous work for the first 4 components (figure 3).

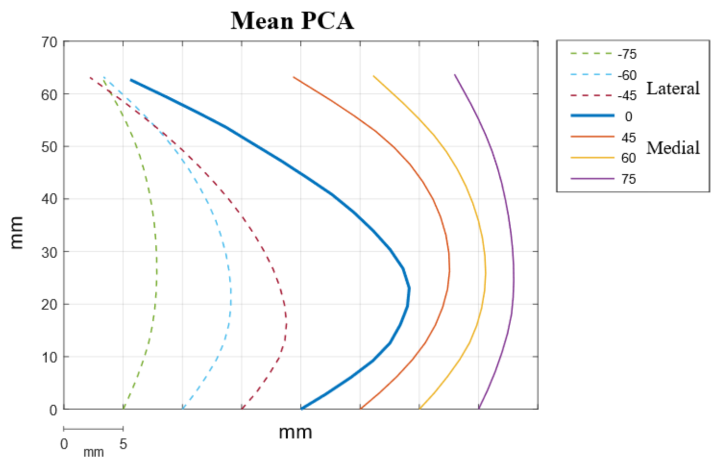

Figure 2 - Mean arcs from the PCA model at different angles along the breast surface (75° (medial side), to −75° (lateral side)).

After evaluating possible linear relationships between each PCA component against each individual patient feature, a strong linear relationship ($R^2 = 0.95$) was found, as in the previous study[7], between the first PCA component, alpha, and the breast thickness retrieved from the DICOM header. When comparing the linear relationship between our present study (y = 9.69x-609) with our previous work (y = 9.67x-539)[7] we found that the fitting parameters were very similar. This suggests that the results found previously still hold when applied to a new dataset and different DBT unit, confirming that indeed the characterization of the breast shape did not vary when the breasts were compressed by a different system. By having this linear relationship, thickness values from the DBT images can then be used to help recreate the breast surface, together with the other PCA components mean values. For the remaining cases, no other relevant linear relationship was found (p-value > 0.05).

By using a multiple regression approach, we expected to find sets of patient features (from the seven collected) on which each PCA component was dependent on. However, fitting the seven features together in this regression model did not provide a better description of the dependencies between the PCA components and the patient features. The values for the R-squared were still low (R^2 <0.90) for all components except for alpha (there was a slight increase of the R^2 from 0.95 to 0.97), where we already know that a strong relation exists with the breast thickness. This increase in the case of alpha could mean that some of these features might have the potential to explain the changes in the arcs generated by the different PCA components, but also that they are still not sufficient to obtain a good correlation. Adding more data to this analysis might give us a better insight on the relationship between PCA components and patient features, as well as searching for other parameters that might justify breast shape deformations once compressed. Additionally, one might consider testing a non-linear correlation instead.

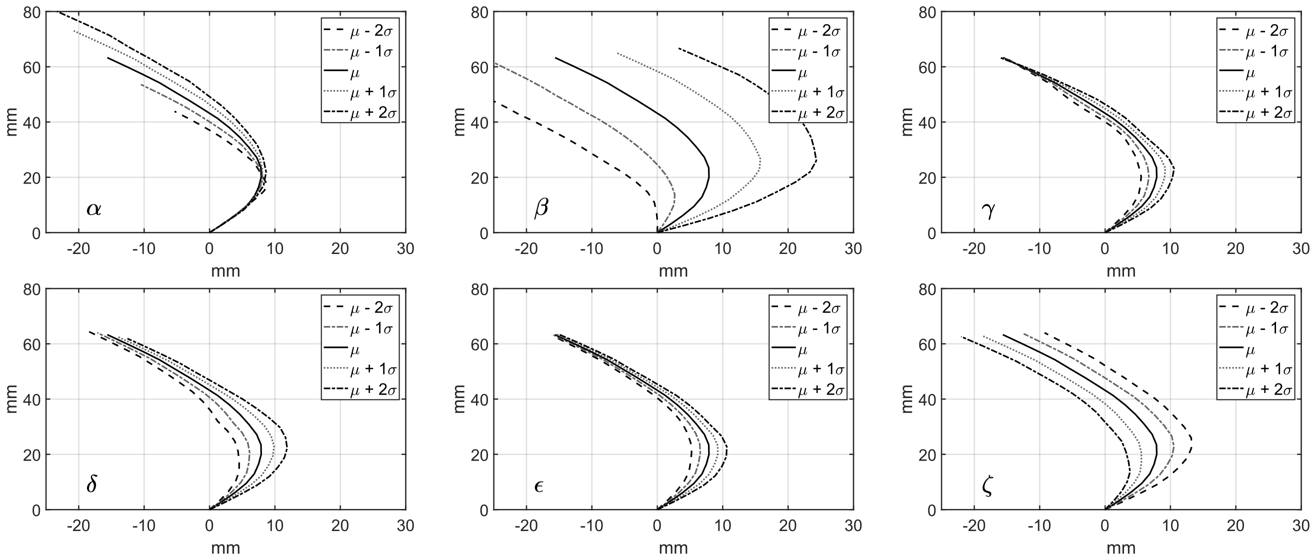

Figure 3 - Arcs generated by varying the first six PCA parameters of the model. Each parameter was set to the mean value (μ) found across our population, as well as to μ ± one standard deviation (σ) and μ ± 2σ.

4. Conclusion

The approach taken in the current work achieved better coverage of the breast surface and allowed for testing the PCA model previously developed in a different DBT system with a larger dataset. Furthermore, an interim analysis on possible correlations between the PCA components and patient data, without the use of the SL cameras, was performed. Nevertheless, the results showed that, even though it was possible to replicate past experiments, 70 cases are still too few to predict PCA components based on patient features or even that such a correlation is not present. To test this, future work will include the collection of additional data and also testing for the presence of non-linear correlations.

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