Creation of Computational Breast Phantoms with Extracted Abnormalities from Real Patient Images

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Abstract. The current contribution presents an approach for creation of complex computational breast phantoms, with included breast abnormalities. In-house developed and validated software tool, called *BreastSimulator*, is used to create different models of healthy breasts, by varying parameters like shape, size, duct tree features, Cooper ligaments, skin, etc. Separately, different 3D tumour models are constructed from segmented tumour regions on sets of real tomosynthesis images from real patients. A semi-automatic algorithm was developed to segment the abnormalities in the images. The algorithm applies a series of image processing operations and region-growing techniques with minimal interaction from the user to find the areas of the lesions. The flat tumour images are then correctly stacked and stored in a 3D voxel matrix, matching the desired resolution. Relevant information about the lesion (voxel size, matrix size, geometrical centre, etc.) is also saved. Selected tumour models are then inserted at various locations into the computational models of the healthy breasts. Examples of simulated mammographic and tomosynthesis images from such breast phantoms are presented to illustrate the potential of the proposed approach. Combining mathematical breast modelling with segmented real 3D tumour shapes results in the creation of realistic breast phantoms. The approach allows implementation of multiple scenarios and unlimited number of cases, which can be used for further software modelling and investigation of breast imaging techniques.

Keywords: breast phantom, breast simulator, tumour segmentation.

1 Introduction

Early diagnosis of breast cancer can significantly increase the probability for successful treatment of the disease. Therefore, many efforts are focused on improvement of the existing imaging techniques or investigations of new ones. Along that, anthropomorphic phantoms, either physical or computational, are widely used in the relevant research studies.

This work presents an approach for creation of complex computational breast phantoms, with included breast abnormalities.

Fig. 1. A screenshot from the *BreastSimulator* software application, showing (a) the application user interface for modelling the duct tree and (b) the compression of a breast phantom, generated with the this tool.

2.3 Segmentation algorithm

The different 3D tumour models are obtained through segmentation of tumour regions on sets of real tomosynthesis images from real patients. For the purpose, an in-house semi-automatic algorithm is used to segment the abnormalities in the images (Dukov *et al.* 2017; Dukov *et al.* 2016).

The algorithm consists of four major steps shown in **Fig. 2**: i) loading the clinical data, ii) pre-processing of the data, iii) segmentation of the tumour masses, and iv) creation of a 3D tumour voxel matrix.

The algorithm requires an input from the operator (user) for the initial selection the range of images at which the segmentation algorithm will be performed, as well as, a rough selection of Region of Interest (first image from the range of images). The region selection is then automatically transferred to the rest of the images.

Fig. 2. Segmentation steps for the in-house developed algorithm.

Results from the different steps of the segmentation procedure are shown in **Fig. 3** and present how the procedure extracts the lesion for a given slice. Finally, a 3D volume, containing the segmented shape is created and stored into a MATLAB data file.

Fig. 3. Results from the different steps of the segmentation algorithm obtained after: i) thresholding; ii) morphological processing; iii) region growing; iv) interpolation.

2.4 Insertion of extracted abnormalities into computational breast phantoms

The results of applying the segmentation procedure on patient data are in fact computational models of breast abnormalities, represented as Boolean three-dimensional

voxel matrices with voxel values of 1 where the abnormality is present. The user selects the place in the breast volume (phantom) where the breast abnormality will be integrated. Then the properties of the abnormality are changed in such a way that the abnormality is smoothly integrated to the surrounding tissues within the breast volume. The degree of smoothing of each voxel from the abnormality matrix depends on its distance from the centre. The more distant the voxels are, the higher degree of smoothing is achieved.

3 Results and Discussions

3.1 Phantoms

For this experimentation we generated a medium in size breast phantom with a 25% glandular tissue without skin (33% with skin) as shown in **Fig. 4a**. The number of Cooper ligaments (presented as ellipsoids) is approximately 1000, while the glandular duct tree is composed of approximately 8000 cylinders of different sizes. The model is then transformed into a 3D breast voxel matrix, which contained glandular, adipose and skin tissues. Subsequently, this voxel-based breast model is subjected to a compression simulation which resulted in a breast phantom with a thickness of 4cm, as shown in **Fig. 4b**.

Fig. 4. Modelled breast phantom of (a) average breast (590 ml), (b) compressed version of the computer breast model.

3.2 Segmented models

An extracted tumour model from the segmentation algorithm is shown in **Fig. 5a,b**.

Fig. 5. An extracted model obtained from the segmentation procedure: a) 2D segmentation tumour area from a single slice; b) 3D visualization of the same segmented abnormality, shown from different angle views.

The tumour mass shown in **Fig. 5** is segmented from 12 slices, each one with a thickness of 1mm. The size of the segmented tumour is 7.3mm x 12.3mm x 12mm. The size of the 3D matrix containing it is 96 x 155 x 22 voxels. The mass was as-

essed subjectively by a physician (visual inspection) before introducing it into the computational breast phantom.

3.3 Computational breast phantoms with extracted abnormalities

The 3D model

The selected tumour model is then inserted into the computational breast phantom (**Fig. 6**).

Simulations

Breast tomosynthesis images with the composed breast phantom with an introduced abnormality are simulated by using *XRAYImagingSimulator* (Bliznakova *et al.* 2010). 26 x-ray projection images of the software phantom are produced with energy of 20keV for monochromatic x-ray beam. Scatter and detector responses are not simulated. Distances from the source to the breast support table, where the phantom is placed, and to the detector surface, are 600 mm and 650 mm, respectively. The size of the images is 1200 x 1200 pixels with pixel size of 0.085 mm x 0.085 mm. A mammography image obtained at craniocaudal view is shown in **Fig. 7a**. The 26 projection images are then used with the FDKR software application, which is an application for reconstruction of tomosynthesis slices (Bliznakova *et al.* 2016). **Fig. 7b** and **Fig. 7c** show the reconstructed tomosynthesis images at two different planes of the reconstructed breast phantom.

Fig. 6. Breast phantom with an introduced abnormality: a) 3D view; b) 2D view.

Fig. 7. Images obtained with the software phantom: (a) craniocaudal projection image, and tomosynthesis images reconstructed at two different phantom heights: (b) at the isocentric plane, (c) at the plane, where the abnormality is located.

4 Conclusions

Combining mathematical breast modelling with segmented realistic 3D tumour shapes results in the creation of realistic breast phantoms, which can be used to generate realistic simulated x-ray projection images. The approach allows implementation of multiple scenarios and unlimited number of breast tumour cases, which can be used for further software modelling and investigation of breast imaging techniques.

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