Comparison of the Image Compounding Methods for the Multi-Angle 3-D Ultrasound Imaging

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Abstract

The main goal of the paper is to compare the image compounding methods to minimise the artefacts arising in the Multi-Angle Conventional Ultrasound Imaging (MACUI) due to the system configuration. The MACUI method used for 3-D object imaging and the introduced imaging artefacts are described. Different ways of the image compounding by intensity averaging are presented in the work. Implemented methods of image compounding were tested for different types of objects mimicking soft tissue. The comparison allowed to determine the most appropriate method of intensity averaging in the compounding method. The method can be used to reduce the presence of image artefacts and enhance the quality of the resulting slices which are used to create 3-D volume of an object structure in MACUI method.

Keywords: Multi-Angle Conventional Ultrasound Imaging, 3-D ultrasound imaging, image compounding, soft tissue

1. Introduction

Breast cancer is one of the most common women’s health issue worldwide. Different radiological methods are continuously being developed and researched to improve an early detection of malignancy in women's breasts. The extensive research is conducted using ultrasound as it is the non-invasive and non-ionizing method of breast imaging. Ultrasound tomography (UT) is a novel technique providing several new ultrasound modalities for breast tissue imaging. These modalities use transmission, reflection and scattering of ultrasound to obtain comprehensive information about tissue structure [1]. The prototype of the hybrid ultrasound tomography scanner developed in Poland by DRAMIŃSKI S.A. company in cooperation with Wroclaw University of Science and Technology team is currently at the stage of clinical evaluation [2]. Despite the advantages of using ultrasound tomography, its sensitivity and specificity are still worse in comparison to Magnetic Resonance Imaging (MRI), Mammography and Ultrasound [2]. Thus, the embedding a new method that uses B-mode ultrasound modality in the ultrasound tomography scanner is desirable. So far, Full Angle Spatial Compound Imaging (FASCI) method has been designed to take advantages of B-mode modality [3]. FASCI utilizes specially designed transducer ring array for the ultrasound tomography device [5, 6]. The method benefits from use of existing hardware, however, the geometry of the system as well as not optimal transducers characteristics for B-mode imaging cause the limitation of the method. The study on a new method, which could be employed in ultrasound tomography device, was carried out by the authors. Multi-Angle Conventional Ultrasound Imaging (MACUI) method described in the next section has been designed and tested for potential use in UT device and for reducing the limitations of the FASCI.

MACUI method shows many advantages over FASCI, including direct acquisition of more informative transversal and sagittal sections, use of probe and electronics optimised for B-mode scanning and lack of circular geometry limitation such as backscattering and reflection distortion. Nonetheless, some artefacts are present in obtained images. Spatial Compounding (SC) is a known and widely used method of enhancing quality of ultrasound B-mode imaging. The authors aim to use the SC in MACUI method in order to minimise artefacts arising at the centre of the slices obtained from the combination of the images acquired for the θ and $(\pi - \theta)$ angles. Quantitative comparison of different ways of compounding by image intensity averaging was performed in terms of usability of the SC method for the MACUI.

2. MACUI method and artefacts

Multi-Angle Conventional Ultrasound Imaging involves the rotational imaging system to collect the set of data about examined structure under different horizontal angles θ. For each angle a vertical section of an object is acquired. The probe of the conventional B-mode system can be placed in a different position in relation to the object under examination. Therefore, three basic configurations can be distinguished. Vertical top and vertical bottom configurations are equivalent to each other and depend on imaging system configuration. In the first one, the object slices are acquired by the probe moving over the top of the object, while in the second configuration, under the bottom. The third configuration is a vertical lateral one. In this configuration, the vertical slices are obtained from the probe moving around the lateral surface of the object. Vertical top and lateral configurations are schematically shown in Fig. 1. Probe is being rotated around Z-axis. Vertical projections of an object are acquired for the entire turnover with a predetermined angle step. The vertical bottom configuration with the centre of the ultrasonic probe moved aside the rotation axis can be potentially used as an additional, conventional ultrasound modality in UT device. In this configuration, the entire probe is placed outside the rotational axis. This provides large enough imaging area to be applicable for breast screening and allows using a breast holder needed for stretching the breast during examination procedure [7]. Considering that vertical top and bottom configuration are equivalent, the vertical top was used in the work in order to qualitatively evaluate the spatial compounding methods for MACUI.

The obtained images are then assembled into coronal projection of a structure. The rows taken at the specific heights from all of the images carry the data about specific coronal section.

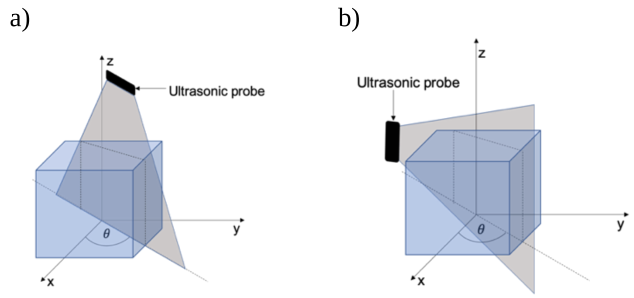

Figure 1. The idea of acquiring images of object's sections in the vertical top (a) and vertical lateral (b) configuration of the MACUI

The radial and angular position of the pixels in each row corresponding to the particular height are converted to the Cartesian coordinates to create the image of the structure's coronal section.

Tissue mimicking phantoms were submerged in the water tank and placed on the absorption material to minimise reflection from the bottom of the tank. The probe was mounted to the rotational mechanism that allowed for setting the required angles. SmartUs Telemed B-mode scanner was used as imaging device. The linear ultrasound probe with transducer array of 4 cm length with the centre frequency set to 7.5 MHz was used. Measurement set-up used to acquire test images for further evaluation of SC is presented in Fig. 2a. Test objects were scanned in two positions only. The second position was at angle ($\pi - \theta$), while θ stand for an angle of the first position. This is shown in Fig. 2a by presenting the second position of the ultrasonic probe in shadowed colours. It can be noticed that the imaging area of the probe at the initial position is overlapped by the imaging area for the probe at angle ($\pi - \theta$). This region is the subject of interest in the work (Fig. 2b). It is important to combine both images in this area with, ideally, neither artefacts nor distortion. This influences the quality of a resulting slice of the object, which would be used later for reconstruction of the entire object's 3-D volume.

In the preliminary study on the MACUI method, the opposite images were compounded in the most straightforward and simple way. Both images were truncated at the rotation axis and concatenated together side by side. Despite the simplicity and implementation easiness of this method, it exhibits the image artefact in its centre. When the sectoral scanning is used for the imaging process in the described configuration, the ultrasound waves reach the object at the rotation axis at different angles and through different acoustic paths. That causes the object's shape distortion due to different average sound speed throughout an acoustic path and different angles of incident. As a result, truncated images are not well matched at the centre of the resulting slice. Figure 2b shows the example of the tissue mimicking phantom's slice obtained in MACUI method by image truncation. The area where the artefacts are the most visible has been cut and presented separately. It has to be mentioned that the phantom is not a very complicated structure. When more complicated tissue structure with smaller inclusions in this area would be considered, artefacts can significantly reduce their continuity or even prevent a viewer from differentiating them from surrounding tissue in reconstructed 3-D image.

a) b)

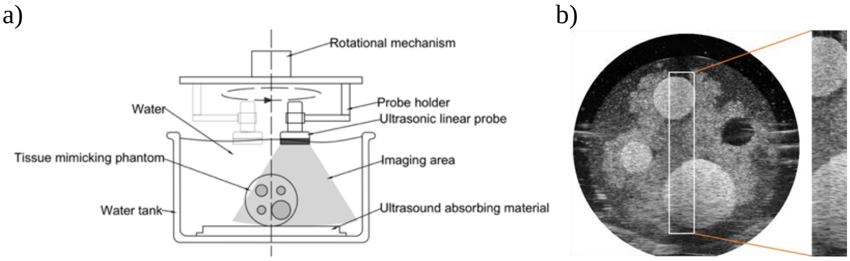

Figure 2. Measurement set-up for SC evaluation in MACUI method (a).
Example of arising artefacts in MACUI utilizing image truncation

3. Materials and compounding methods

Multi-angle Compound Imaging (MACI) is a commonly used method to enhance the quality of ultrasound imaging. Usually, the method involves a single probe employing a beam steering system to alter the angle of the ultrasound beams during measurement. The object of interest is scanned under several angles (usually 3 to 9) and then images are combined to obtain a single image [3]. Spatial Compounding method minimises a number of artefacts presented in the conventional B-mode imaging. Speckle noise, reflection artefacts from specular reflectors, acoustic shadows and angle dependency reduction, as well as an increase in contrast resolution, boundaries visualisation, image understanding and general image quality over conventional B-mode ultrasound have been reported in a number of works [3-6]. Intensity averaging of images is a well-established way to obtain spatially compounded images in ultrasound B-mode scanning techniques. Because of this, the authors attempted to perform the qualitative evaluation of different types of intensity averaging as the first step in study to improve the quality of the images and reduce the artefacts arising in proposed MACUI method. What significantly differentiates the spatial compounding approach in MACUI method from MACI is a probe placement. In contrast to MACI, in the MACUI method two images are taken from opposite sides of object vertical symmetry axis (Fig. 1a). Therefore, the images are less correlated with each other and there are larger differences in the acoustic path of the ultrasound waves approaching the structure in the overlapped area. This results in higher amount of shape distortion differences between images.

The selected ways of compounding by image averaging are Arithmetic, RMS, Geometric and Weighted Average. In the Arithmetic method, the intensity of each pixel in the overlapping area is the simple arithmetic average of the intensity of corresponding pixels in the images that have been compounded. It can be expressed by the equation:

$$I_{Avg\_x,y} = \frac{1}{N}\sum_{n=1}^{N} I_{x_n,y_n} \underset{for\,N=2}{=} \frac{I_{x_1,y_1} + I_{x_2,y_2}}{2} \tag{1}$$

In general, image intensity averaging can be performed for N images, however MACUI configuration presented int this paper involves two images in a compounding task. Indices x, y indicate the position of the pixel on the compound image, while indices x_1, y_1, x_2, y_2 stand for the placement of the pixels in the corresponding images. RMS method uses the root mean square to calculate the pixels intensity in the compounded image. This is described by the equation for the general case of N images involved in compounding process and specified for two images:

$$I_{RMS\_x,y} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} I_{x_n,y_n}{}^2} \underset{for\ N=2}{=} \sqrt{\frac{I_{x_1,y_1}{}^2 + I_{x_2,y_2}{}^2}{2}} \tag{2}$$

Similarly, the equation defines the geometric mean used in geometric averaging of the images' intensity pixels:

$$I_{Geo\_x,y} = \sqrt{\prod_{n=1}^{N} I_{x_n,y_n}} \underset{for\ N=2}{=} \sqrt{I_{x_1,y_1} \cdot I_{x_2,y_2}} \tag{3}$$

The last method utilizes specially adapted weighted average for spatial compounding in MACUI method:

$$I_{WAvg\_x,y} = \sum_{n=1}^{N} W_{n,x,y} \cdot I_{x_n y_n} \underset{for\ N=2}{=} W_{1,x,y} \cdot I_{x_1 y_1} + W_{2,x,y} \cdot I_{x_2 y_2} \tag{4}$$

In general case of N images $W_{n,x,y}$ are the weighting coefficients for the specific pixel at (x, y) point in compounded image. Index n corresponds to the particular image for which the coefficient is used. This method is equivalent to the smooth images blending in the compounding area. The vertical line in the centre of the compounding area is the simple average of the pixels engaged in compounding. For each row in the compounding area, the weighted coefficients for the left-side image decrease when index x increases and increase when index x decreases. It happens with the step S. For the right-side image increasing and decreasing of the weighted coefficients take place in opposite order. Dependence between $W_{1,x,y}$ and $W_{2,x,y}$ and step S are defined accordingly:

$$W_{1,x,y} = 1 - W_{2,x,y} \tag{5}$$

$$S = \frac{1}{M_y + 1} \tag{6}$$

where M_y is a number of pixels in a row at y height inside the compounding region. The linear change in coefficient had been chosen arbitrary as the most straightforward method of image blending.

Two self-made agar gel phantoms were used as a tissue mimicking objects. Dimensions and view of the phantoms are presented in Fig. 3. The main part of both of the phantoms were made from 10% Petrygo radiator fluid and water solution, with addition of 3 g of agar powder per 100 ml of the mixture (No. 5 on Fig. 3a). Inclusions in each phantom were made to obtain different acoustic properties of a gel. In the first one, the cylindrical parts 1, 2 and 3 were made by changing the Petrygo radiator fluid concentration, which altered the speed of ultrasound in the gel. The proportion of the Petrygo radiator fluid in parts 1, 2 and 3 are 15%, 20% and 5% accordingly. In the second one, those parts were prepared by addition of a different portion of graphite powder with the particle sizes range of 0 – 60 µm. This allowed for changing the ultrasound wave attenuation coefficient of obtained gel. The amount of graphite powder added to parts 1, 2, 3 are 4.55 g/100 ml, 2.5 g/100 ml and 6.35 g/100 ml accordingly. In both phantoms, part 4 was left as an empty cylinder. The cylinders were filled with the water during measurements. Fig. 3b shows the examplary photo of the real phantom with graphite powder inclusion.

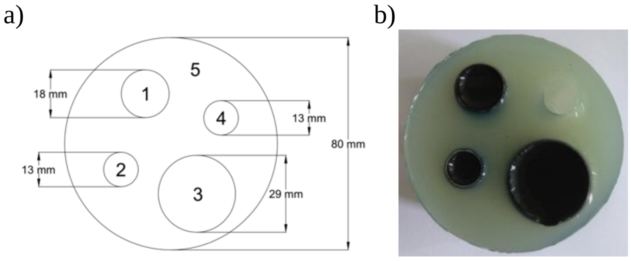

Figure 3. Dimensions of self-made agar gel phantoms (a)
and the photo of the real made agar phantom with the graphite powder inclusion (b)

4. Results and analysis

In Fig. 4, the phantom with addition of the graphite powder is presented. Numbers 1, 2, 3, 4 correspond to Arithmetic, RMS, Geometric and Weighted Average methods accordingly. No additional processing like filtering or denoising image had been used during imaging process of individual images used in spatial compounding. Unexpected agar gel nonuniformity in the inclusions' surrounding area (No. 5 in Fig. 3a) has come out during measurement. This unpredicted effect is beneficial from the images evaluation point of view, as such irregularity in the structure can reveal the artefact which could not be visible otherwise.

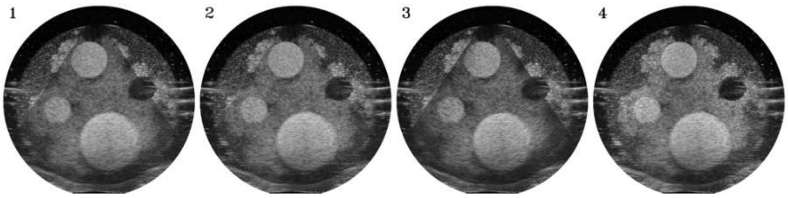

Figure 4. Result of the compound imaging of the phantom with addition of the graphite powder in the MACUI method without image normalization procedure

It can be seen that in the results of the first three methods the boundaries of compounding region are clearly visible. Due to this fact, the additional normalization was made to scale the images' intensity in both parts, inside and outside of compounding region. The normalization factor was 255, which is the maximum value of the 8-bit grey scale images used in compounding procedure. The results after normalization are shown in Fig. 5. The image obtained with the Weighted Average method is not affected by boundaries' intensity inhomogeneity as they are effectively blended with the appropriate weighted factor. At the boundaries, data from the image for which the phantom was scanned closer the centre of B-mode device imaging area are of the greatest importance. The entire image was normalized for this reason. As can be seen, the normalization procedure significantly improves the resulting image in the Arithmetic, RMS and Geometric Average methods. However, in the Average and Geometric methods boundaries of the SC region are still highly visible, but the improvement over methods 1 and 3 is significant. Additionally, the normalization procedure slightly increases the overall brightness in SC region for tested phantoms.

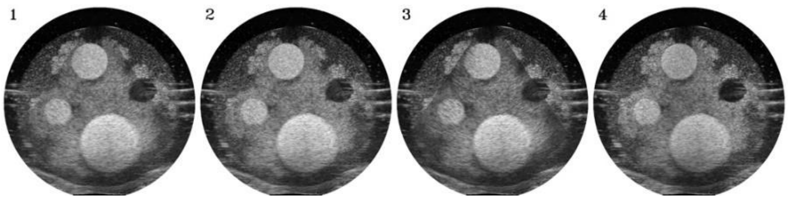

Figure 5. Result of the compound imaging of the phantom with addition of the graphite powder in the MACUI method with image normalization procedure

The best results, regardless of the normalization procedure usage in SC for the MACUI, were obtained with the Weighted Average method due to the lack of intensity differences at the SC region's boundaries.

The results of SC for phantom with different proportion of the Petrygo radiator fluid are shown in Fig. 6.

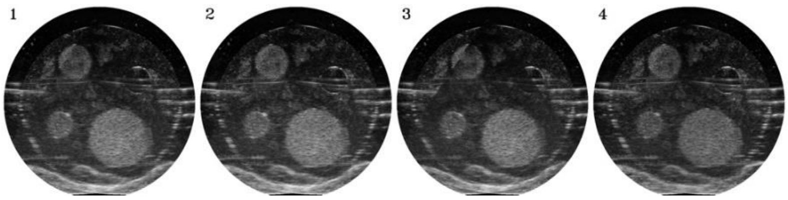

Figure. 6. Result of the compound imaging of the phantom with different proportion of Petrygo radiator fluid in the MACUI method image normalization procedure

Imaging results of the phantom presented in Fig. 6 obtained by the Arithmetic (1) and Geometric (3) average methods are not sufficient in terms of the consistency of the SC region's boundaries like in the results presented in Fig. 5. The result obtained by the RMS method significantly reduced the issue of boundaries' inhomogeneity, but not completely. The best result in this term was obtained with the use of the Weighted Average method. Moreover, the increase in inclusions' boundaries blurring can be noticed comparing to the phantom presented in Fig. 5. This is due to different average speed of ultrasound through different path in the phantom. This results in larger amount of shape distortion of the individual inclusion scanned under different perspectives. Therefore, the SC by the intensity averaging is not sufficient for structures in which the speed of ultrasound varies. Additional processing for shape differences reduction would be required in this case.

5. Conclusions

Examples discussed in the paper show that the spatial compound imaging without additional processing can be successfully used in the Multi-Angle Conventional Ultrasound Imaging approach unless the speed of sound does not vary in the structure. The best results were obtained with the proposed Weighted Average method. The compounded image is not affected by the intensity inhomogeneity at the boundaries of SC region. Relatively small amount of inclusions' shape distortion in tissue mimicking object can be effectively minimised with using the Weighted Average method, resulting in satisfactory imaging quality of the individual structure's slice obtained in MACUI method.

In case of sound speed differences across the structure, the significant blurring effect on inclusions' boundaries is exhibited. This reduces the possible usage of the MACUI method without additional processing aiming to reduce differences in inclusions' shape between images. In case of real tissue structure, both attenuation coefficient and speed of sound change. This minimise the usability of the simple SC methods to be successfully applied in MACUI method. Nevertheless, the most suitable for the MACUI method and possible further improvement is proposed Weighted Average method as it is not affected by artefacts at the SC region's boundaries. Future work will cover the study on the adequate method of shape differences reduction between images.

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