Using Data Fusion to Characterize Breast Tissue

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ABSTRACT

New ultrasound data, obtained with a circular experimental scanner, are compared with data obtained with standard X-ray CT. Ultrasound data obtained by scanning fixed breast tissue were used to generate images of sound speed and reflectivity. The ultrasound images exhibit approximately 1 mm resolution and about 20 dB of dynamic range. All data were obtained in a circular geometry. X-ray CT scans were used to generate X-ray images corresponding to the same "slices" obtained with the ultrasound scanner. The good match of sensitivity, resolution and angular coverage between the ultrasound and X-ray data makes possible a direct comparison of the three types of images. We present the results of such a comparison for an excised breast fixed in formalin. The results are presented visually using various types of data fusion. A general correspondence between the sound speed, reflectivity and X-ray morphologies is found. The degree to which data fusion can help characterize tissue is assessed by examining the quantitative correlations between the ultrasound and X-ray images.

Keywords: Ultrasound, computed tomography, X-rays, data fusion, breast cancer, tissue characterization.

1. INTRODUCTION

The Karmanos Cancer Institute is developing an ultrasound device for measuring and imaging acoustic parameters of human tissue. The device has been developed to the engineering prototype stage and has been used to perform a variety of experiments. This paper discusses the experimental results relating to tissue characterization, that is, the use of ultrasound (US) to identify and quantify various tissue types, with a specific focus on diagnosing breast cancer. The overall goal of the project described herein, is improved breast tissue characterization. Current breast US is limited to mass evaluation, whereas mammography also detects and guides biopsy of malignant calcifications. Neither approach provides quantitative tissue identification.

Improved tissue characterization could result in a reduction of the estimated one million benign biopsies performed each year in the United States[1], costing up to several billion dollars[2]. Most breast calcifications, for example, are benign and comprise ~ 80% of stereotactic biopsies guided by mammography[3]. Ultrasound has the potential for tissue characterization so that benign masses are clearly identified thereby obviating the need for biopsies in such cases.

Currently, high-resolution US images of the breast are performed in the reflection mode at relatively high frequencies (roughly 5 – 15 MHz). Reconstruction of reflection ultrasound images relies upon acoustic impedance differences in the tissue and includes only direct backscatter of the ultrasound signal. Resolution and tissue contrast of current US continues to improve with denser transducer arrays and better image processing but direct tissue characterization remains elusive.

2. MATERIALS AND METHODS

The initial technical goal of the CURE program was to provide sub-millimeter resolution and quantitative tissue characterization using both reflection and transmission US. To that end, the Karmanos Cancer Institute (KCI) contracted with the Lawrence Livermore National Laboratory (LLNL) to build an engineering prototype capable of acquiring 3-D US data. LLNL was also tasked with developing the initial algorithms for image reconstruction. The engineering prototype and some of the initial results are described in a previous paper[4]. Additional algorithms are being developed in collaboration with physicists at Groupvelocity, LLC. The associated image reconstructions are being used to test the feasibility of characterizing tissue, as described below.

2.1 The Data

Data were acquired by scanning a cadaveric breast that was placed in formalin and sealed in a 10-cm diameter, cylindrical container (courtesy TechniScan Inc). The cadaveric breast specimen was scanned with the CURE scanner at a frequency of 1.5 MHz using 2 microsecond pulses. The relatively low frequency of 1.5 MHz was used in order to better penetrate the target and broaden the beam angle while retaining sub-mm spatial resolution. The receivers and transmitters were positioned along a ring trajectory having a diameter of 20 cm. A total of 1280 receiver positions and 320 transmitter positions were used, corresponding to lambda/4 and lambda spacing, respectively. The target was placed at the center of the ring with the long axis of the cylinder oriented vertically relative to the plane of the ring. Each data set represents a 2-D slice through the phantom. The ring plane could be translated in the vertical direction allowing for 3-D reconstructions from stacked 2-D planes of data. The phantoms was also scanned with a clinical reflection ultrasound unit (GE Logiq 600) and a clinical CT scanner (GE Lightspeed Quad detector array). The CT scans were performed at 1.25 mm slice thickness. All CURE scans were performed at 10 millimeter slice thickness to generate multiple tomographic images per phantom.

2.2. The Algorithms

Acquiring the data is only the first step leading to tissue characterization. Producing quantitative ultrasound images requires the ability to accurately model the physics of US pulse propagation in tissue. In this study, the acoustic properties of sound speed, attenuation and reflectivity were determined and imaged using a family of algorithms. The algorithms are grouped into two basic types and are described in the companion paper in these proceedings.

3. RESULTS

X-ray imaging: Figure 1a shows an X-ray CT image generated with 1.25 mm slice thickness through the normal breast specimen showing predominantly fatty tissue with thin internal fibrous bands. The formalin liquid is evident on the right hand side of the image. A relatively thin region of chest-wall muscle forms the boundary between the breast and the liquid. The X-ray image is calibrated in Houndsfield units. The formalin mixture can be used as a reference level of X-ray absorption against which to qualitatively assess the absorption levels of the various tissue types. The X-ray absorption scale is rendered such that the lighter the shading the greater the absorption. The cylinder boundary shown in the image represents the sample container and has a diameter of 10 cm. This dimension sets the spatial scale of the image.

US reflectivity: Figure 1b is a standard B-scan ultrasound image of the specimen. Figure 1c is the CURE image obtained at 1.5 MHz using only the reflected data. The multi-view nature of the CURE data allows for a much better definition of the reflecting surfaces in the excised breast. Reflectivity scales with the rate of change of the acoustic impedance. The grey scale associated with this image is rendered such that the whiter the shading the greater the reflectivity. It is interesting to note that the reflecting surfaces are made up almost entirely of thread-like bands having thicknesses of the order of 1 mm. Figure 2 shows a close-up of the reflection image. Note the fine structure associated with the fibrous material of the breast. The diameter of the cylinder (the outer circular ring) is 10 cm. The individual bands are resolved to approximately 1 mm thickness. The fibers represent regions of the breast tissue where sudden changes in acoustic impedance cause strong reflections. Beyond reflectivity, this data does not contain any other information for characterizing tissue. The 10 cm cylinder boundary is evident in figures 1c and 2.

Imaging of Sound Speed: Figure 1d is the CURE image made using only transmitted data. The algorithms described in the companion paper (these proceedings)[5] were used to construct images of sound speed from recordings of the transmitted pulses. Increasing sound speed is represented as lighter areas on the gray scale. The formalin mixture and the boundaries of the breast tissue are evident in the image. The breast tissue is characterized by sound speed variations and generally has lower sound speed than the formalin mixture. The formalin mixture can be used as a reference sound speed against which to compare variations in sound speed for the various tissue types in the breast. The overall range in sound speed of 1450 m/s (black) to 1550 m/s (white).

Data Fusion: Figure 3 shows a superposition of the reflection image and the sound speed image. The sound speed is shown in grey scale with the darkest portions representing a sound speed of about 1450 m/s. The lightest regions have speeds of about 1550 m/s. The grey scale on the reflection image indicates reflectivity with white representing highest reflectivities. Figure 4 shows side-by-side comparisons of reflection image superimposed on the X-ray CT image (4a) and the US sound speed image (4b), respectively. In the case of 4a, it was not possible to align the images accurately because the target had shifted somewhat between the US scan and the X-ray CT scan (the excised breast can "slosh" around inside the cylinder – it is not fixed). Nevertheless, a number of interesting correlations can be observed, as described below in a more detailed analysis and discussion.

4. DISCUSSION

The feasibility of submillimeter resolution ultrasound has been demonstrated for the engineering prototype phase of the CURE program (see companion paper)[5]. We now discuss the potential for tissue characterization using morphology based on reflectivity, sound speed and X-ray absorption. We have tried to present images with consistency, such that lighter shades for reflectivity, sound speed and density represent increasing quantities, as in conventional US and CT.

A comparison of US reflectivity with US sound speed and X-ray absorption reveals a number of results that point to the potential for tissue characterization. These results are based on analysis of the four regions identified with arrows in figure 3.

Region 1: Region 1 is indicated by the topmost arrow in figure 3. This region is characterized by a dense concentration of fibrous bands (figure 2). According to the visible woman project, such bands should have a sound significantly higher than that of the surrounding fatty tissue. The enhanced sound speed, indicated by lightening of the grey scale in figure 1d, in this region, confirms that these bands are indeed characterized by higher sound speed. Figure 4a shows an overlay of US reflectivity and X-ray absorption. The dense concentration of fibrous bands shows up in both the X-ray image and the US image. This region is characterized by high US reflectivity, high levels of X-ray absorption and US sound speed that is slightly lower than that of the formalin mixture. The actual sound speeds of the fibers are probably higher since the lower spatial resolution of the sound speed images (3mm compared to 1 mm fiber thickness) tends to dilute the sound speed by averaging the fiber speeds with those of the surrounding fatty tissue.

Region 2: In region 2, indicated by the second arrow from the top in figure 3, the medium is the formalin liquid within which the breast is embedded. This liquid is also characterized by a sound speed higher than fatty tissue (figure 1d) and the overall light shading of this region is consistent with the results expected from the visible woman project. The absence of strongly reflecting surfaces (figure 2) is also consistent with the liquid nature of this region. Finally, the uniform X-ray absorption in this region and its intermediate value also points to a relatively uniform liquid. These observations suggest that data fusion can be used to identify and characterize liquids in human tissue. Such characterization would greatly aid in the identification of liquid-filled cysts, a task that is currently limited to interpreting anechoic regions in conventional B-scan imaging.

Region 3: The third arrow from the top points to strands of tissue on the inside edge of the folded breast tissue. It is characterized by a sound speed higher than that of formalin mixture and much higher than that of fatty tissue which makes up the bulk of the breast by volume (figures 1d and 3). Its X-ray absorption properties are variable but contain regions that absorb more than the formalin (figure 1a). The US reflectivity suggests that this tissue also contains a concentration of fibers. The nature of the tissue combined with its high sound speed and high X-ray absorption suggest that it is highly fibrous tissue, possibly near the chest wall which was likely to have been excised along with the fatty tissues. . These correlations are illustrated in the fused images in figure 4.

Region 4: Finally, region 4 is indicated by the lowest arrow in figure 3 and points to a branch of fibers sitting in a high sound speed trough (figure 3). The trough is most likely just a dilution of the fiber branch brought about by the lower spatial resolution of the sound speed data. The high X-ray absorption associated with this trough confirm the presence of the branch of fibers. The morphology of these features combined with the reflectivity, sound speed and X-ray absorption point to the potential for using data fusion to identify (masses within the normal) fibrous & ductal architecture in the breast.

5. CONCLUSIONS AND FUTURE WORK

It has been shown that high quality US images, resulting from the experimental CURE scanner, have the potential to characterize breast tissue through data fusion. This work is in progress and the analysis presented here is highly qualitative. Future work will concentrate on quantitative calibration of the X-ray absorption, US reflectivity and sound speed. Future work will also concentrate on better alignment of data through controlled US/X-ray scans and will include MR imaging as well.

6. ACKNOWLEDGMENTS

The authors would like to acknowledge the support of several individuals in this work. They are Dr. John Boone at U. C. Davis Medical center for the X-ray CT images and Dr. Alex Babkin and Prof. Robert Duncan (University of New Mexico) for their help with the image reconstructions. Funding for this project was provided by philanthropic support of the Karmanos Cancer Institute.

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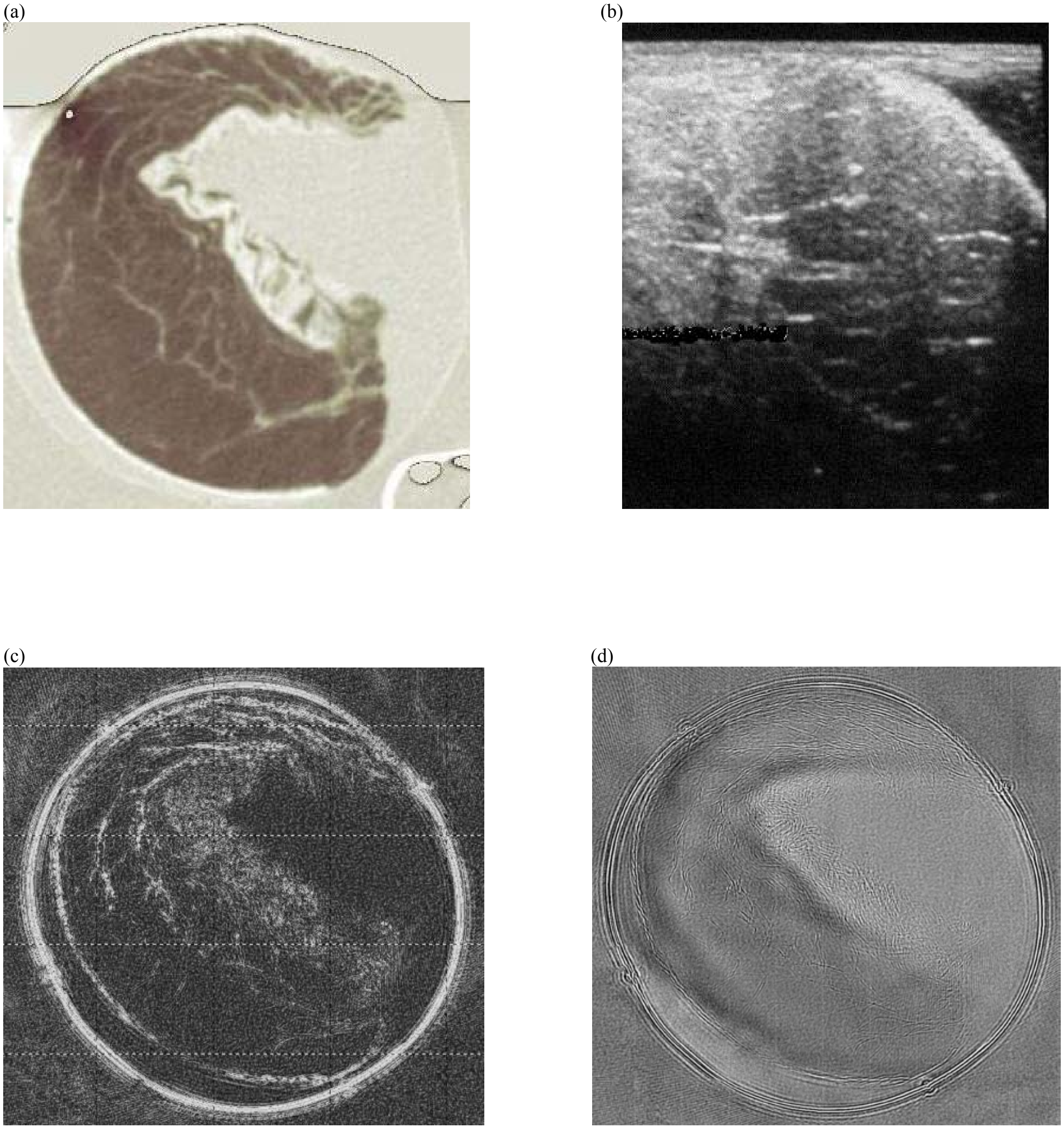

Figure 1: (a) the X-ray CT scan, (b) conventional B-Scan, (c) CURE US reflection image, (d) CURE US sound speed image.

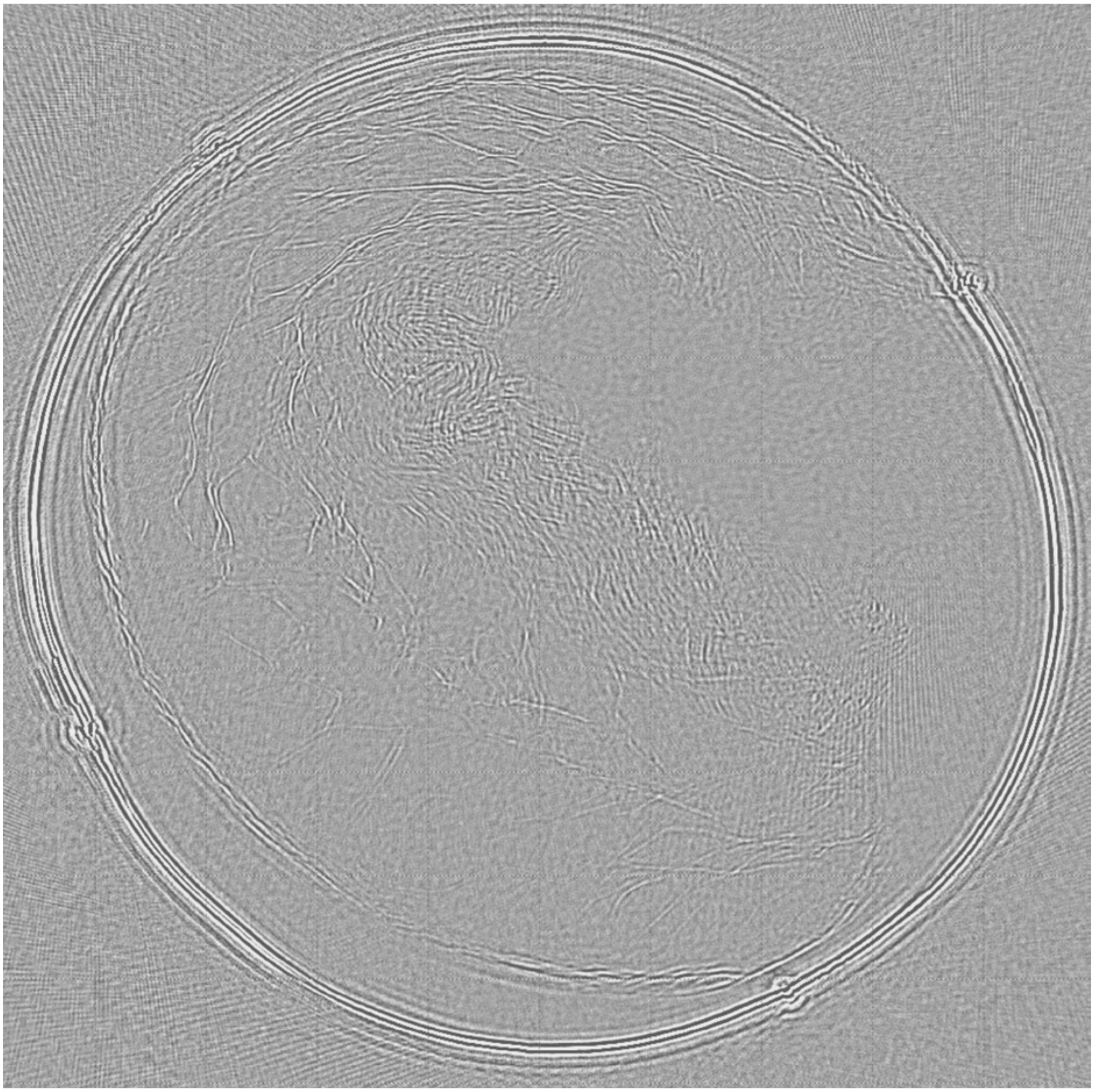

Figure 2: Detailed view of the CURE US reflection image.

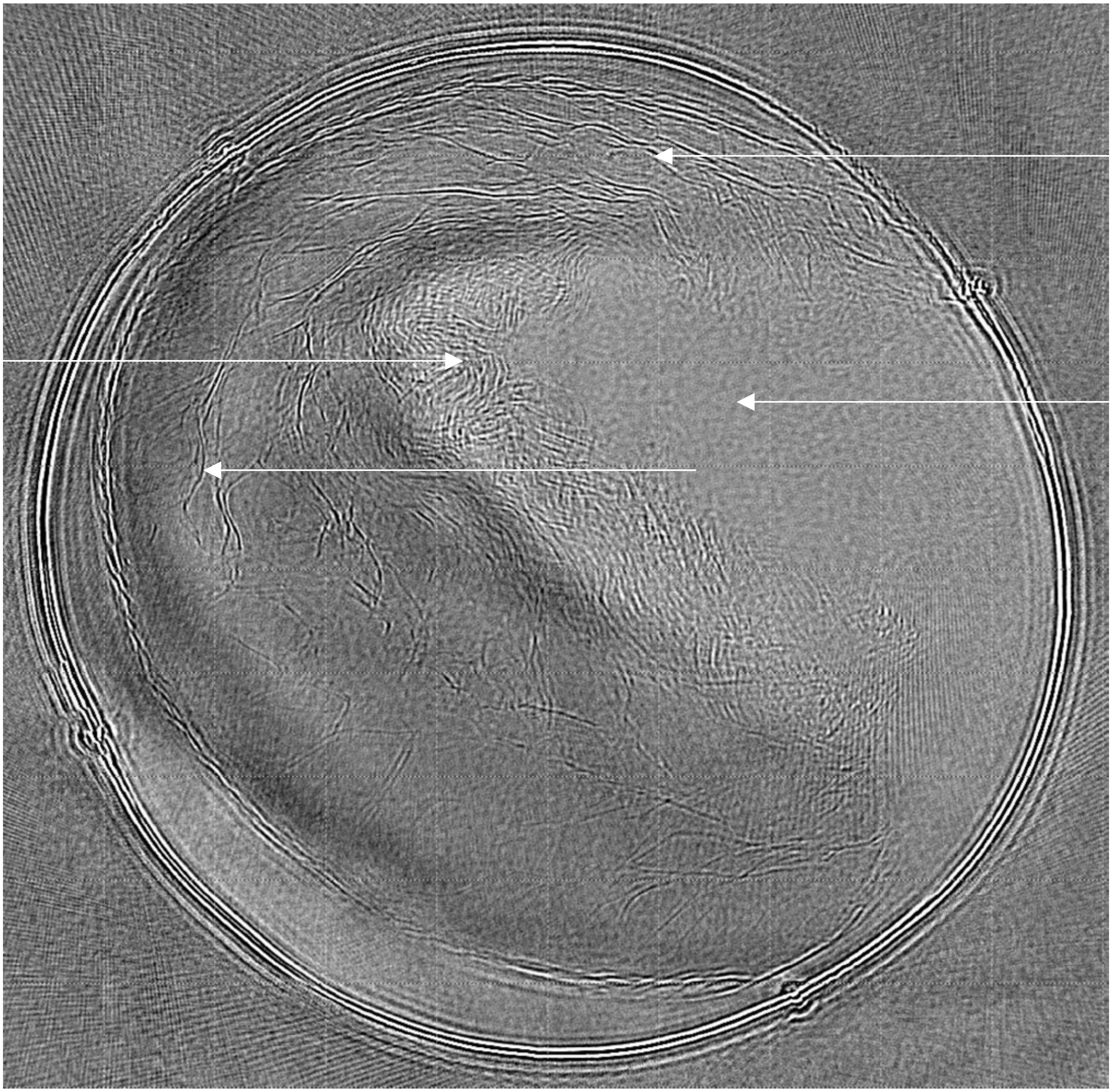

Figure 3: Detailed view of the CURE reflection image superimposed on the CURE sound speed image. The four regions, discussed in the paper, are identified with the white arrows.

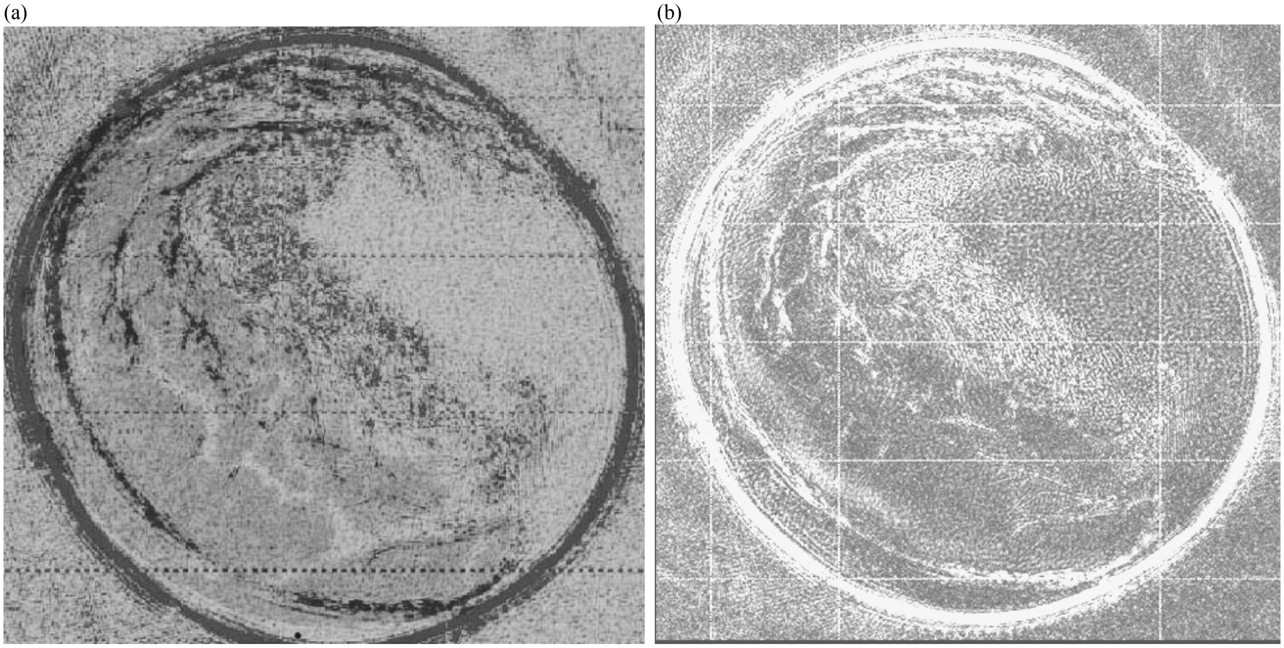

Figure 4: (a) US reflection image superimposed on the X-ray CT scan. The US reflection image has its grey scale inverted for better representation of the superposition. (b) US reflection image superimposed on the sound speed image.