USCT reference data base
Conclusions from the first SPIE USCT data challenge and future directions

Ruiter, Nicole V; Zapf, Michael; Hopp, Torsten; Gemmeke, Hartmut; van Dongen, Koen; Camacho, Jorge; Herraiz, Joaquín L.; Perez Liva, Mailyn ; Udías, Jose

DOI
10.1117/12.2293063

Publication date
2018

Document Version
Final published version

Published in
Progress in Biomedical Optics and Imaging - Proceedings of SPIE

Citation (APA)
Ruiter, N. V., Zapf, M., Hopp, T., Gemmeke, H., van Dongen, K., Camacho, J., Herraiz, J. L., Perez Liva, M., & Udías, J. (2018). USCT reference data base: Conclusions from the first SPIE USCT data challenge and future directions. In N. Duric, & B. C. Byram (Eds.), *Progress in Biomedical Optics and Imaging - Proceedings of SPIE: Medical Imaging 2018 :Ultrasonic Imaging and Tomography* (Vol. 10580). SPIE. https://doi.org/10.1117/12.2293063

PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

USCT reference data base: conclusions from the first SPIE USCT data challenge and future directions

Ruiter, Nicole, Zapf, Michael, Hopp, Torsten, Gemmeke, Hartmut, van Dongen, Koen W., et al.

Nicole V. Ruiter, Michael Zapf, Torsten Hopp, Hartmut Gemmeke, Koen W. A. van Dongen, Jorge Camacho, Joaquín L. Herraiz, Mailyn Perez Liva, Jose M. Udías, "USCT reference data base: conclusions from the first SPIE USCT data challenge and future directions," Proc. SPIE 10580, Medical Imaging 2018: Ultrasonic Imaging and Tomography, 105800Q (6 March 2018); doi: 10.1117/12.2293063

SPIE.

Event: SPIE Medical Imaging, 2018, Houston, Texas, United States

USCT reference database: conclusions from the first SPIE USCT data challenge and future directions

Nicole V. Ruiter[1], Michael Zapf[1], Torsten Hopp[1], Hartmut Gemmeke[1], Koen W.A. van Dongen[2], Jorge Camacho[3], Joaquín L. Herraiz[4], Mailyn Perez Liva[4], Jose M. Udías[4]
[1]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2]Laboratory of Acoustical Wavefield Imaging, Delft University of Technology, Delft, the Netherlands
[3]Ultrasound Systems and Technology Group, Spanish National Research Council, Madrid, Spain
[4] Nuclear Physics Group, University Complutense of Madrid, Madrid, Spain

ABSTRACT

Ultrasound Computer Tomography is an exciting new technology mostly aimed at breast cancer imaging. Due to the complex interaction of ultrasound with human tissue, the large amount of raw data, and the large volumes of interest, both image acquisition and image reconstruction are challenging. Following the idea of open science, the long term goal of the USCT reference database is establishing open and easy to use data and code interfaces and stimulating the exchange of available reconstruction algorithms and raw data sets of different USCT devices. The database was established with freely available and open licensed USCT data for comparison of reconstruction algorithms, and will be maintained and updated. Additionally, the feedback about data and system architecture of the scientists working on reconstruction methods will be published to help to drive further development of the various measurement setups.

Keywords: Ultrasound computer tomography, data challenge, open science, open data

1. INTRODUCTION

The Ultrasound Computer Tomography (USCT) reference database and platform aims on applying available image reconstruction algorithms on provided USCT data in order to establish intercommunication and standards for an open data interface. The data sets and software for data access are available via the USCT database home page and the linked data and code repository [1]. The long term goal of this work is to build a free and open licensed reference database which is available for the whole community. We expect this to enable reproducible comparison of image reconstruction algorithms and USCT systems, and to establish user-friendly and easy to use interfaces, standards and data formats between the different USCT systems and their reconstruction algorithms, software and data formats.

As kick-off for the USCT database, we initiated a USCT data challenge at SPIE Medical Imaging 2017 [2]. The aim was to apply existing image reconstruction algorithms to real 2D and 3D USCT data and bring together experts from the USCT community to identify best practices, as well as to establish specifications for interfaces and carry out a first comparison of reconstructed images. Since the first online publication of the USCT database and the SPIE challenge, the group of the Spanish National Research Council, which developed the MUBI system [3], joined the donators of data. The USCT data challenge resulted in six posters presented at the meeting and three detailed field reports of data users. It was accompanied by a discussion panel. While in our previous publication the initial status of the database and the contributing USCT systems were described, this paper gives an update on the current status of the database extended by data of the MUBI system. Furthermore we present the results of the first SPIE USCT data challenge panel discussion and possible future directions.

The materials of the USCT database are provided using a free and open license, i.e. the BSD 3-clause license [4] for code and data, allowing free use and publication of results. The data sets may remain with the participants, and can be used for any research and purpose. Further publication and results should follow good academic practices and cite the paper of the USCT data challenge 2017 [2]. All data sets are provided with data access interface software. The source code is freely available and an issue tracker is provided at a Github repository [5].

Medical Imaging 2018: Ultrasonic Imaging and Tomography, edited by Neb Duric,
Brett C. Byram, Proc. of SPIE Vol. 10580, 105800Q · © 2018 SPIE
CCC code: 1605-7422/18/$18 · doi: 10.1117/12.2293063

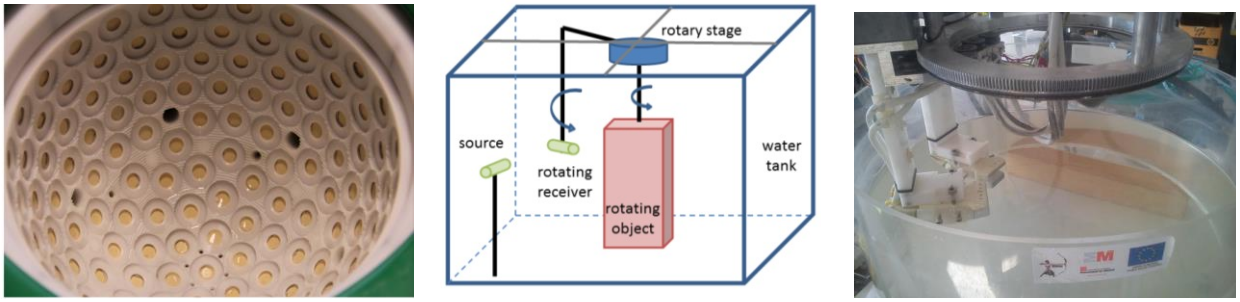


Figure 1: The three scanning systems of the USCT database which are currently providing data; (left) 3D KIT USCT: 3D system, single transducers with 2.5 MHz center frequency semi-elliptical aperture with 24 cm diameter and 17 cm height; (center) Delft Breast Ultrasound Scanner (DBUS): 2D system, single transducers with 0.5 MHz center frequency, emitter radius 0.3 m and receiver radius 0.1 m; (right) MUBI system: 2D system, two 3.5 MHz, 128 elements and 0.22 mm pitch arrays 95 mm radius, pulse-echo and through-transmission modes.

2. METHODS

Currently three systems with very different transducer aperture and ultrasound frequency range provide raw data sets for the USCT database. The systems are depicted in Figure 1.

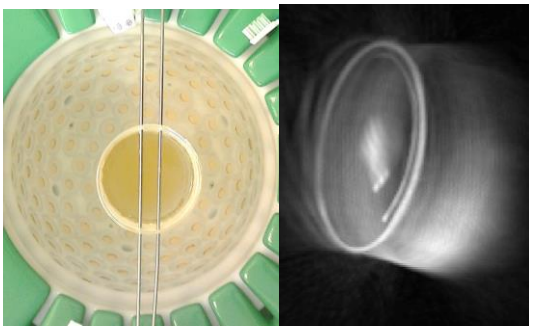
The KIT's 3D Ultrasound Computer Tomography system (3D USCT) has a semi-ellipsoidal 3D aperture [6]. Approx. spherical wave fronts are generated by each emitter at 2.5 MHz and with a bandwidth of 1.5 MHz at -6 dB. The semi-elliptical aperture has a diameter of 26 cm and a height of 16 cm. Rotational and translational movements, so-called aperture positions, of the complete sensor system create additional virtual positions of the transducers. The 2041 individual transducers are either operated as emitters (628) or receivers (1413). The transducers have opening angles of 38.2° (standard deviation ±1.5°) at -6 dB.

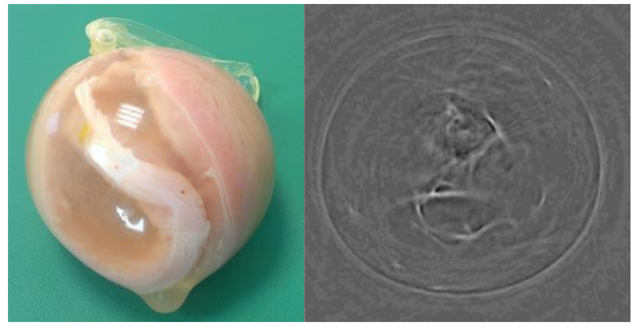
The Delft Breast Ultrasound Scanner (DBUS) consists of a water tank with dimensions 0.75 m x 0.75 m x 0.65 m with a water level of 0.45 m. On top of the system, two rotary stages are mounted. The first rotary stage rotates the object, the second the receiver (0.5 MHz, Panametrics V318). The source, which is identical to the receiver, is mounted at a fixed position in the corner of the tank. A relatively low center frequency of approx. 0.5 MHz is applied as the system aims at testing full-wave form inversion methods [7].

The Multimodal Ultrasound Breast Imaging System (MUBI) is intended to be a flexible platform for multi-modal ultrasound imaging research, mainly oriented to breast diagnosis [3]. The system is formed by two 3.5 MHz, 128 elements and 0.22 mm pitch arrays (P2-4/30EP, Prosonic, Korea) that rotate with 95 mm radius into a water tank. While only one array can be used as emitter, both of them can act as receivers, allowing pulse-echo and through-transmission operation modes. The system is able to perform emission and reception beamforming in real-time implementing image compounding. The acquisition scheme for USCT follows the fan-beam approach of CT systems.

In total, ten data sets have been made available, six data sets were obtained with the system from KIT, two data sets with the system from the TU Delft, and two with the MUBI system of the Spanish National Research Council. Photos and diagrams of the phantoms and example reconstructions are shown in Figure 2.

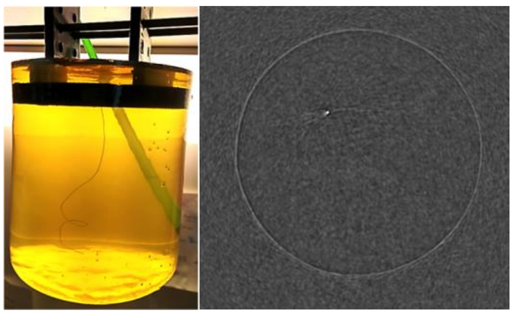
The 3D KIT USCT data consists of six data sets. Three data sets of different phantoms are provided, each with an empty scan acquired at the same day as the phantom and with identical settings of the system's parameters. The "gelatine 3" phantom consists of a gelatin phantom with approx. 1515 m/s and a diameter of approx. 0.07 m at the bottom and 0.10 m at the top, a height of approx. 0.10 m. The gelatin was embedded in a plastic cup. Two inclusions were filled with water. In the "turkey phantom" two olives without stones where embedded into a turkey steak. The steak was then embedded in a condom and filled with gelatin. The resulting phantom has a diameter of approx. 9 cm. The turkey steak had an approximate sound speed larger than 1550 m/s while the olives had a sound speed of approx. 1450 m/s.

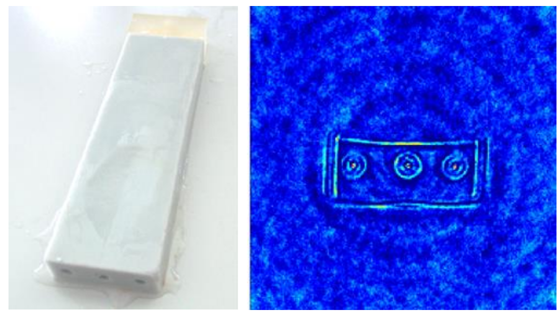




Gelatine 3

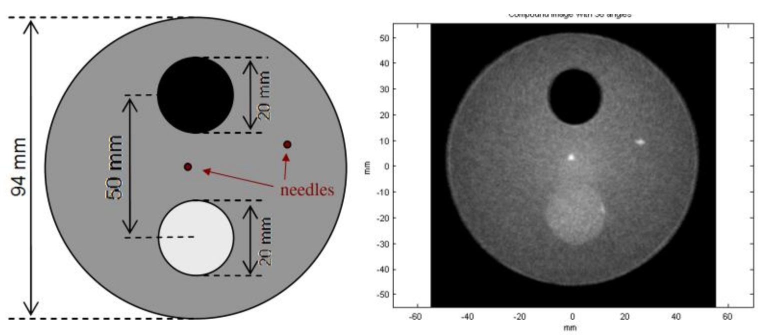
Turkey





Nylon thread

Agar



Tissue mimicking

Figure 2: Phantoms scanned; (left) photo, (right) reconstruction using different reconstruction algorithms. From top left to bottom right: KIT: gelatin 3 phantom reconstructed with SAFT in low resolution and displayed as maximum intensity projection to enhance the visibility of the bottom of the plastic cup, turkey phantom reconstructed with SAFT, and finally nylon thread phantom with speed of sound corrected SAFT reconstruction. TU Delft: agar based phantom reconstructed with Delay and Sum; MUBI tissue mimicking phantom reconstructed with full angle spatial compounding.

The “nylon threads” phantom consists of a gelatin cylinder with both diameter and height of approx. 10 cm. In this cylinder, a nylon thread of a diameter 0.2 mm is embedded. The phantom was centrally positioned in the 3D USCT aperture.

The 2D TU Delft USCT data consist of two data sets. The first data set is made in absence of an object as reference measurement. The second data set is an agar based phantom with dimensions of 20 mm x 50 mm. The tissue mimicking phantom has a volume density of mass of approx. 1004 kg/m^3 and a speed of sound of approx. 1479 m/s. The three inclusions were filled with water.

The 2D MUBI USCT data consists of two data sets. The provided phantom data set contains a circular scan of the tissue mimicking phantom, based on water, gelatin, graphite powder and alcohol. It includes a homogenous background with two cylindrical hollows: one filled with water and the other filled with a gelatin preparation with different proportions. Two 0.25 mm diameter steel needles were inserted in the approximate locations shown. Furthermore, a second dataset with the same acquisition parameters but without phantom (i.e. only water) is provided for calibration purposes.

3. RESULTS

In the poster session of the USCT data challenge 2017, six posters were presented, which are available at the USCT reference database webpage [1]. Three field reports were also submitted. They detailed the used data, the applied reconstruction algorithms and reported the experiences and problems in using the data and the interface software. During the test phase, bug reports were also received in direct communication, and followed up by data and code corrections. The templates for the field reports are provided at the USCT reference database webpage [1].

The challenge hosted a panel discussion, which was moderated by N. Ruiter (KIT) and K. van Dongen (TU Delft). The panelists were Thomas Matthews (Washington University in St. Louis, USA), Mailyn Perez Liva (University Complutense of Madrid, Spain), Ken-ichi Kawabata (Hitachi Ltd., Japan), Roberto Janniel Lavarello Montero (Pontifica Universidad Catolica, Peru), Ivana Balic (SonoView Accoustic Sensing Technologies, Swiss), and Neb Duric (Delphinus Medical Technologies). The panelists and the audience discussed the experiences on applying the currently available datasets and future directions during the two-hour session. That discussion is summarized here.

All groups who worked with the data found the provided data format and software interfaces convenient. However, there is a need for a common set of metadata and information that any group offering experimental data should provide. It might be beneficial to offer software interfaces based on open-source software, as currently most interfaces are provided in the proprietary MATLAB scripting language. There was a consensus that the number of provided data sets should be limited in order to allow a fair comparison of algorithms. Furthermore, the dataset quality should be checked before being published. While an independent check by a single entity might not be feasible, an option could be a rating system for the data and/or a platform to exchange experiences, data quality, best practices etc. The discussion also revealed the need for patient data as the complex material composition cannot be represented by phantom data only. Yet, the conditions and restrictions to distribute patient data in public need to be investigated further.

All participants and panelists agreed that a standard phantom would be very beneficial to compare not only image reconstruction algorithms, but also the different USCT systems. Yet, when comparing algorithms in future challenges, a comparison metric should be established to allow specifying the phantom characteristics in more detail. It might also be necessary to have dedicated phantoms for the different USCT imaging modes. They should have limited complexity in order to calibrate image reconstruction methods. Furthermore, synthetic data would be highly welcomed, preferably in the same data format as the experimental data in order to provide an easy transition from synthetic to experimental data. A remaining open question is the manufacturing of phantoms, for which there might be opportunities to collaborate with manufacturers and ultrasound phantom task forces.

A controversial discussion was held on the restrictions of the intellectual property: in general, the opinion was that the data should be provided without restrictions, following the good practices of open access and open science. Yet this might currently not be feasible for companies. There were also mixed opinions on the maintenance of the data: on the one hand the data should not change over time to allow a fair comparison of imaging algorithms. On the other hand, there should be a possibility to correct obvious data errors. A possible solution could be a versioning of datasets and software interfaces (data provenance) which would also guarantee accessibility of revised data for a long time. There was an agreement that the data should be available for several years, yet possibilities to guarantee this requirement need to be investigated.

As an example, the field report of the KIT team (main author Torsten Hopp) is summarized in the following paragraphs. Both datasets of the 2D systems, i.e. the DBUS and the MUBI system, were tested with the KIT reconstruction software. For transmission tomography the ray based algebraic reconstruction techniques (ART) [8] was used and for reflectivity imaging the 3D synthetic aperture focusing technique (SAFT) [9] including, if possible, sound speed correction.

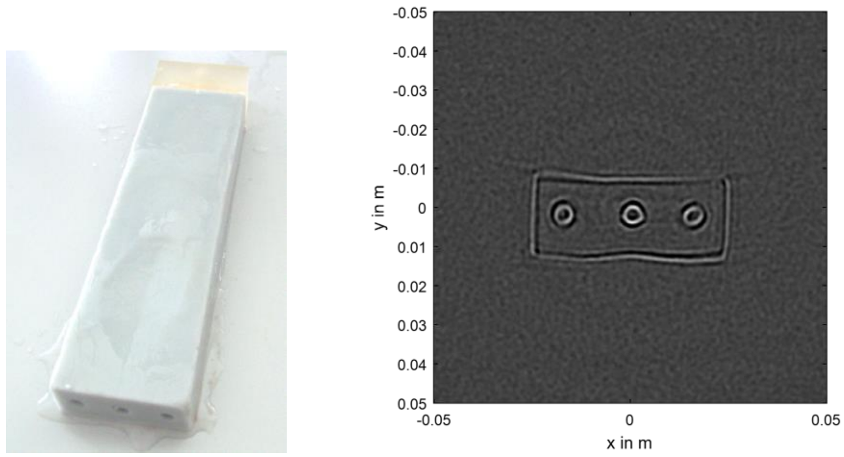


Figure 3: DBUS agar based phantom: photo of the phantom (left) and reconstruction with 3D SAFT (right).

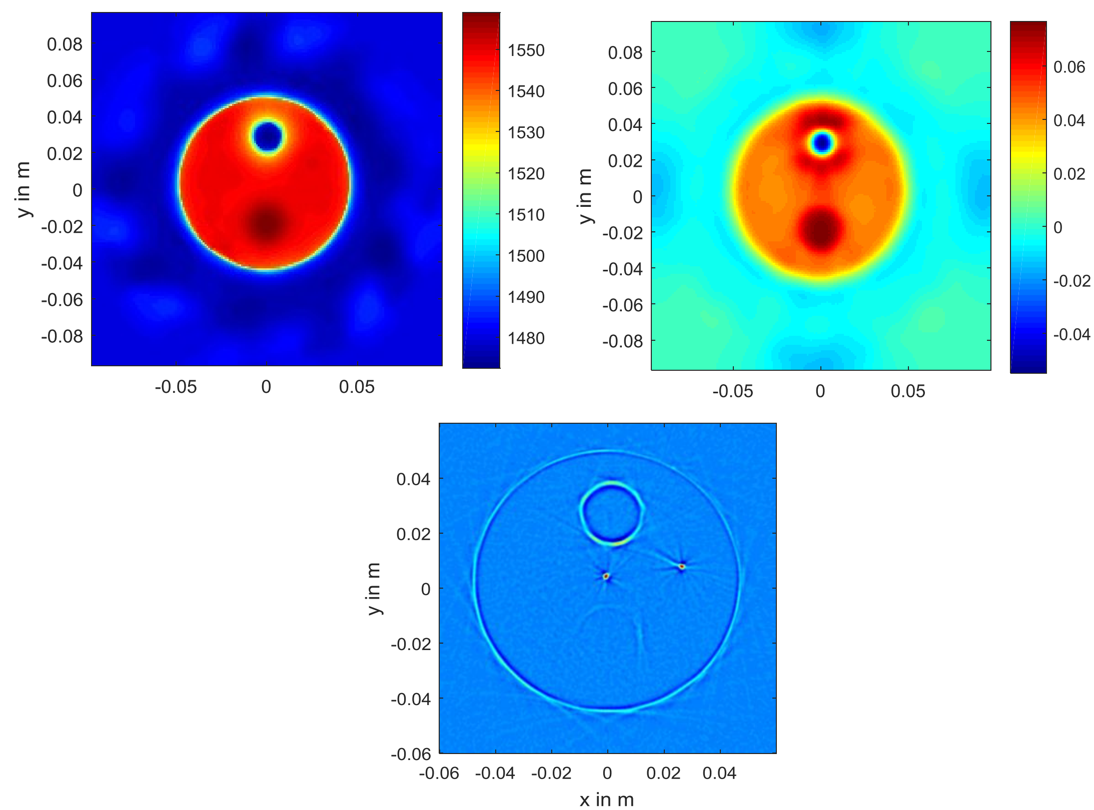


Figure 4: MUBI tissue mimicking phantom: speed of sound in m/s (top left) and attenuation reconstruction in dB/cm (top right); 3D SAFT corrected with reconstructed sound speed and attenuation map (bottom). Axes in m.

For the DBUS dataset sound speed reconstructions performed with ART did not recover the rectangular shape of the imaged phantom. The imaged area appears nearly homogeneously with a sound speed of approx. 1491 - 1493 m/s. The only contrast in the image seems to origin from the different water temperature at which the A-scans were acquired. Consequently, the reflectivity reconstructions were performed with uncorrected SAFT using the average of the given water temperature to compute the sound speed. A-scans for reconstruction were selected by limiting the angle between emitter and receiver normal to 120°. Transmissions signals were removed in a preprocessing step. The pixel resolution was 0.2 mm leading to an image size of 996 x 996 pixels for the area reconstructed to cover the circle covered by the receiving transducer. The computation time using a single NVidia GeForce GTX Titan GPU was approx. 8 s of which approx. 1 s was the computing time for the actual SAFT processing. A detail view of the phantom and its reconstruction is given in Figure 3.

For the MUBI system, sound speed and attenuation images were reconstructed with an ART-based method using a CPU implementation. Figure 4 (top left) shows the result of the speed of sound reconstruction and attenuation reconstruction (top right). The phantom can be clearly distinguished from the water background. The water-filled hollow of the phantom can also be distinguished (lower sound speed area on the right). Due to the limited resolution of the reconstruction method, the embedded needles are not visible. Subsequently we used the reconstructed sound speed maps to apply sound speed corrected SAFT. The results are given in Figure 4 bottom. The inner structures as well as the outline of the phantom are focused considerably better when applying the sound speed corrected SAFT algorithm. Both needles as well as the water-filled hollow are clearly visible, the second hollow with a different mixture of gelatin can be partly delineated in the lower part of the phantom.

The overall experience with the provided datasets was very positive. Using the interface software, the signal data and corresponding metadata could be retrieved within minutes. For both datasets the KIT algorithm interfaces had to be adapted in order to apply reflectivity and transmission reconstruction. This adaption could be done in roughly one day per USCT system and modality. The images were mostly obtained with the basic parameter settings. Optimizing the parameters and methods to enhance the image quality would require additional time and insight into algorithms, systems and data.

The reconstructed images are very promising. Sound speed and attenuation imaging was successfully applied to the MUBI data. Despite the ray approach, which comes with limited resolution, the reconstructed images were able to derive the phantom outline and both large inclusions. The rectangular shape of the DBUS phantom with the same algorithms could not be recovered. Further analysis is needed to identify the potential problems and/or limitations of the method or data. Additional meta data and knowledge about the system (e.g. excitation pulse, possible delays in the signal chain, temperature distribution in the water basin) could contribute to a deeper analysis.

For both systems, the phantoms could be reconstructed with the SAFT-based reflectivity reconstruction. In case of the MUBI data, the data provided was not optimal for reflectivity imaging as there is only the ‘fan beam’ data provided. In consequence mostly the forward scattering is imaged, which limits the resolution and contrast of the reflectivity images.
Due to the GPU accelerated implementation of SAFT, sound speed corrected reflectivity images could be reconstructed in several seconds. Nevertheless there is still a large potential to speed up the reconstructions by optimizing data flows and parallelize data read-in and pre-processing.

In general, the USCT data challenge was very well received. There was consent in the panel that the database should be continued and opened for other groups to provide data and participate in applying their image reconstruction algorithms. The data challenge could continue at SPIE Medical Imaging meetings in future, possibly also with more dedicated challenges for special USCT reconstruction tasks.

4. CONCLUSION

The aim of this work is to provide a freely available and freely licensed USCT database enabling to test and analyze reconstruction algorithms and to compare the performance of competing algorithms. After the successful kick off, further challenges are planned, e.g. challenging the different algorithms by comparison of obtained image quality or computational performance. The data sets are freely available and open licensed, thus they can also be used outside of challenges for evaluation of advanced reconstruction techniques on real data, as well as further development of algorithms for image reconstruction and signal processing. The feedback about data and USCT systems resulting from the use with different algorithms can also lead to drive further developments of the system architecture, e.g. to research the optimization of transducer positioning or limits on signal-to-noise levels. Further challenges are planned, e.g. comparing the image quality and/or computational performance obtained by different algorithms. Finally, other groups are invited to join in and participate.

REFERENCES

[1] http://ipeusctdb1.ipe.kit.edu/~usct/challenge/

[2] Ruiter, N.V., Zapf, M., Hopp, T., and van Dongen, K.W.: USCT data challenge, in Proc. SPIE 10139, Medical Imaging 2017: Ultrasonic Imaging and Tomography, 101391N, 2017.

[3] Camacho, J., Medina, L., Cruza, J.F., Moreno, J.M., and Fritsch, C.: Multimodal ultrasonic imaging for breast cancer detection, Archives of Acoustics, 37-3, pp. 253-60, 2012.

[4] https://opensource.org/licenses/BSD-3-Clause / http://opendatacommons.org/licenses/by/

[5] https://github.com/KIT-3DUSCT/3DUSCT-data-access-script

[6] Ruiter, N. V, Göbel, G., Berger, L., et al.: "Realization of an optimized 3D USCT," In J. D'hooge & M. M. Doyley (Eds.), *Proc. of SPIE*, pp. 796805-796805–8, 2011.

[7] Ozmen, N., Dapp, R., Zapf, M., Gemmeke, H., Ruiter, N.V., van Dongen, K.W.A.: "Comparing different ultrasound imaging methods for breast cancer detection", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 62 (4), pp. 637-646, 2015.

[8] Birk, M., Dapp, R., Ruiter, N.V., Becker, J.: GPU-based iterative transmission reconstruction in 3D Ultrasound Computer Tomography, Journal of Parallel and Distributed Computing 74(1), p. 1730-1743, 2014.

[9] Ruiter, N.V., Kretzek, E., Zapf, M., Hopp, T., Gemmeke, H.: Time of light interpolated synthetic aperture focusing technique, Proc. SPIE Medical Imaging, 2017.