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Evaluation of phase aberration correction for a 3D USCT

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Introduction

3D ultrasound computer tomography (3D USCT) promises reproducible high-resolution images for early detection of breast tumors. A prototype for 3D USCT has been developed at KIT. It has an optimized aperture in form of a semi-ellipsoid to maximize the isotropy of the 3D point spread function (PSF). The prototype provides three different modalities (reflectivity, speed of sound, and attenuation), and high image quality using 2041 transducers within one recording step.

In this setup, with a diameter of 26 cm and height of 17 cm, ultrasound can travel over long distances up to 52 cm. Phase aberrations (PA) due to speed of sound (SOS) variations inside the measuring object (water, different breast tissues) cause many pulses not to overlap in a distinct voxel at the coherent reflectivity reconstruction. Previous research [1] showed that image quality can be increased significantly performing a PA correction. This is done by calculating an average SOS with Bresenham's line algorithm [2] from a SOS volume of the measuring object in several resolutions as approximation. As no quantitative error assessment was done yet, a simulation based on ray tracing is used to quantify their image degradation caused by PA and the effects of the applied PA correction. This is done with the metrics: constrast, resolution and displacement.

Methods

The simulated object contains two regions with different SOS values, see Figure 1: The water with c_w=1500 m/s and the region of a hemispherical approximated breast with c_b=1460-1520 m/s. A point scatterer represents a small cancerous lesion.

- **A-scan generation and reconstruction with SAFT**

The simulation generates the pressure over time signals (A-scans) including the analytic determined PA due to SOS variations. The time-of-fight (TOF) of the ultrasound is determined with equation (1). The A-scan value at TOF is set and convoluted with a Sinc function to represent the pulse applied for image reconstruction (see Figure 1).

$$TOF = \frac{(L_{water1} + L_{water2})}{c_{water}} + \frac{(L_{breast1} + L_{breast2})}{c_{breast}} \quad (1)$$

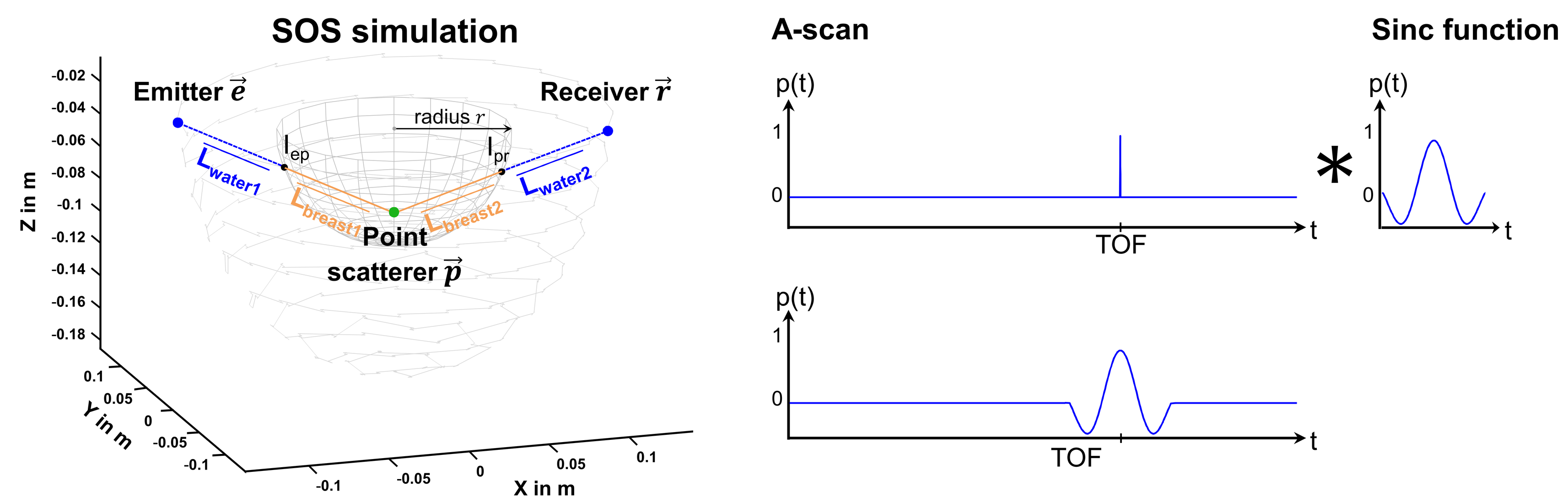


Figure 1. Simulation object (left) and schema of the A-scan generation (right).

The reconstruction of the reflectivity I(x) is done by a Synthetic Aperture Focusing Technique (SAFT) algorithm with equation (2):

$$I(\vec{x}) = \sum_{\forall(e,r)} A_{(e,r)}\left(\mathrm{TOF} = \frac{\|\vec{e}-\vec{x}\| + \|\vec{r}-\vec{x}\|}{\bar{c}_{path(\vec{e},\vec{r},\vec{x})}}\right) \quad (2)$$

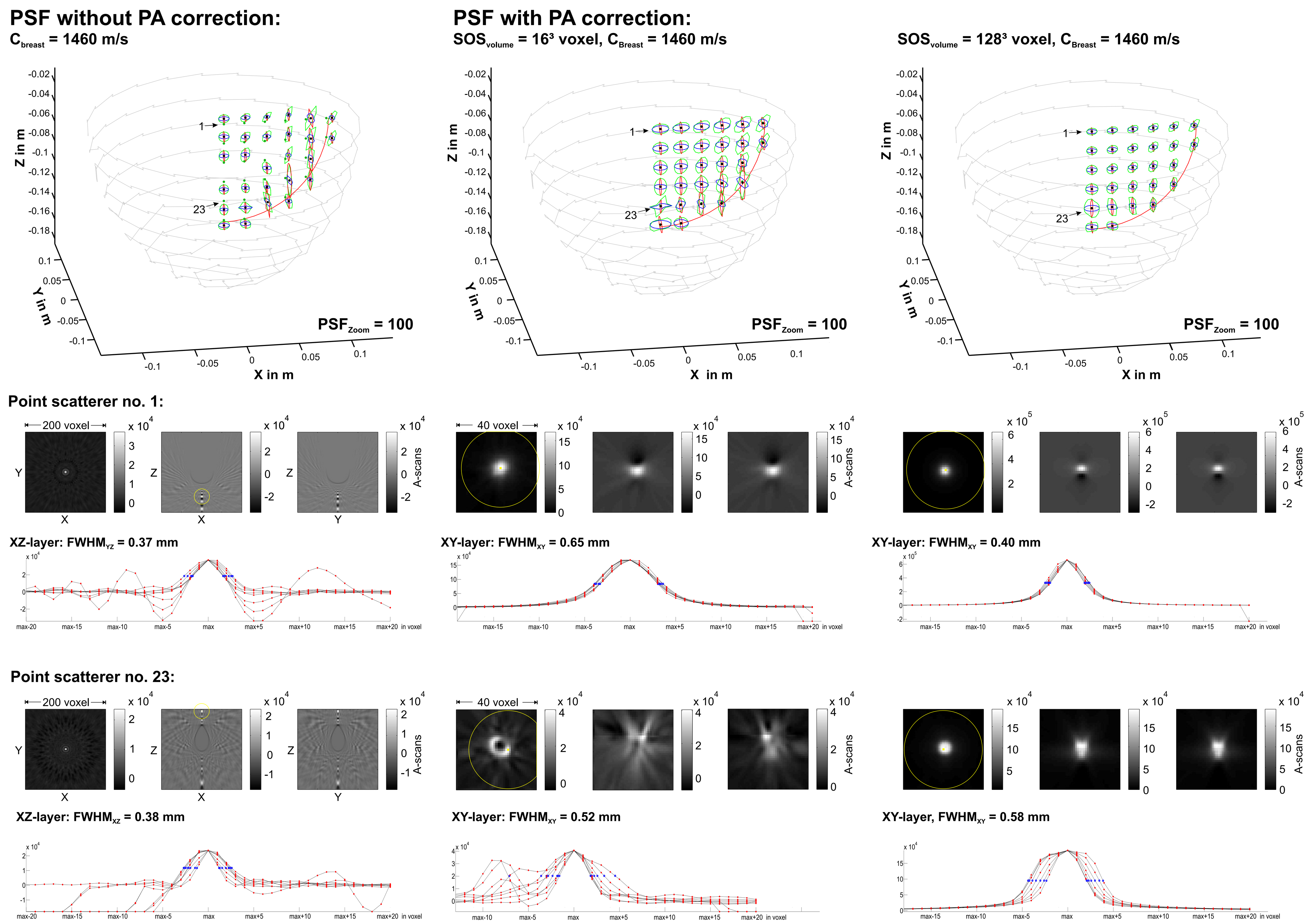
For reconstruction with phase aberration correction a more realistic average speed of sound value was evaluated. The travelled path through the SOS volume results by the harmonic mean of N visited SOS voxels and their local speed of sound values with equation (3):

$$\bar{c}_{path(\vec{e},\vec{r},\vec{x})} = \frac{N}{\sum_{i=1}^{N} \frac{1}{c(\vec{x}_i)}} \quad (3)$$

Results

Used image quality metrics:

- **Contrast:** maximum intensity at one voxel induced by from the point scatterer.
- **Resolution:** full width at half maximum (FWHM) of this contrast distribution.
- **Displacement:** Difference between position of the point scatterer and of the position of maximum intensity.



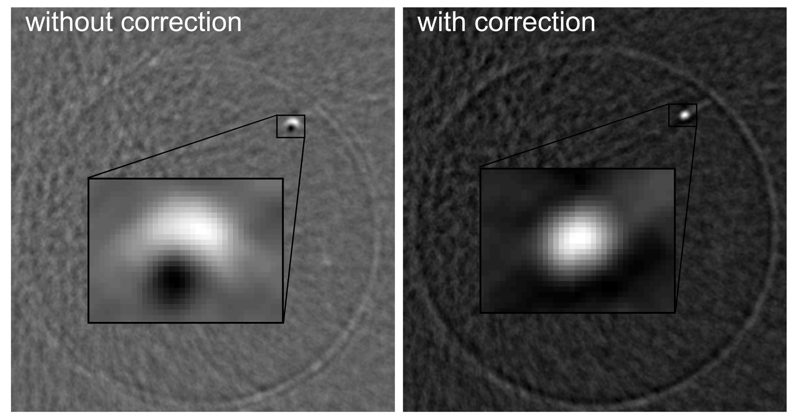
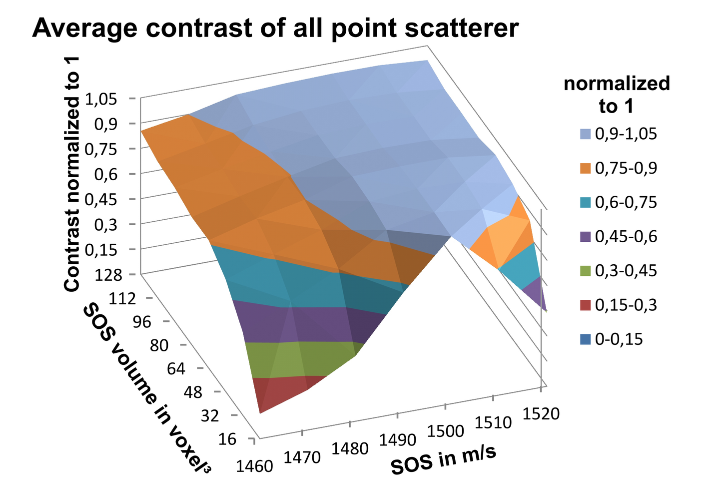
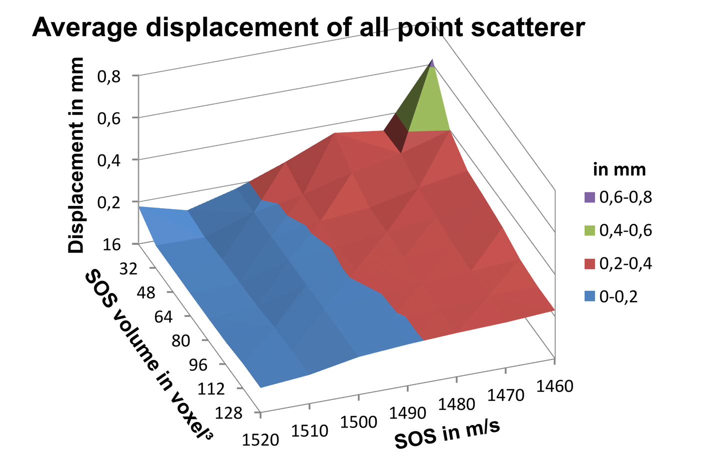
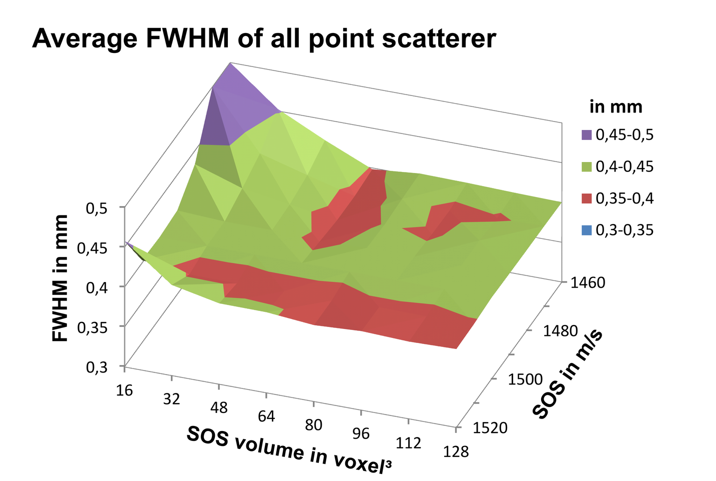


Figure 2. Reconstruction of a thread inside gelantine phantom without (left) and with (right) phase aberration correction.







Conclusion

Several negative influences on image quality could be determined caused by PA for two SOS regions for contrast, position, and resolution. Performing PA correction significantly improve image quality of the simulation, already with a small SOS volume of 32^3 voxels. For SOS volumes from 64^3 voxels on, only a small increase of image quality could be observed. The PA correction was successfully validated with real experimental data see Figure 2. Furthermore the reconstruction should be performed with higher SOS volumes to reach high resolution images also largely differing SOS values.

References

[1] N. V. Ruiter, R. Schnell, M. Zapf, and H. Gemmeke, "Phase Aberration Correction for 3D Ultrasound Computer Tomography Images," in 2007 IEEE Ultrasonics Symposium Proceedings, 2007

[2] J. D. Foley, A. van Dam, et al, Computer Graphics: Principles and Practice, Addison-Wesley Publishing Company, 1996, 2nd Edition in C.