Glasses for 3D Ultrasound Computer Tomography

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Background

At KIT at Karlsruhe we are developing a new imaging method for early breast cancer detection: 3D ultrasound computer tomography.[1] The prototype currently in clinical study trial is called 3DUSCT II. The basic concept is full 3D synthetic aperture focussing (SAFT)[2] with unfocussed spherical waves emitted and received iteratively by individual transducers. The measurement happens in a semi-ellipsoidal formed water-filled container (17cm x 24 cm, height and width)[3] which can be lifted and rotated. The walls are lined with thousands of transducers forming the imaging aperture. The used ultrasound transducers have a resonance frequency at 2.6 MHz, 50% relative bandwidth and a directivity of ± 23° at -6dB.

Figure 1: 3DUSCT II (2013)

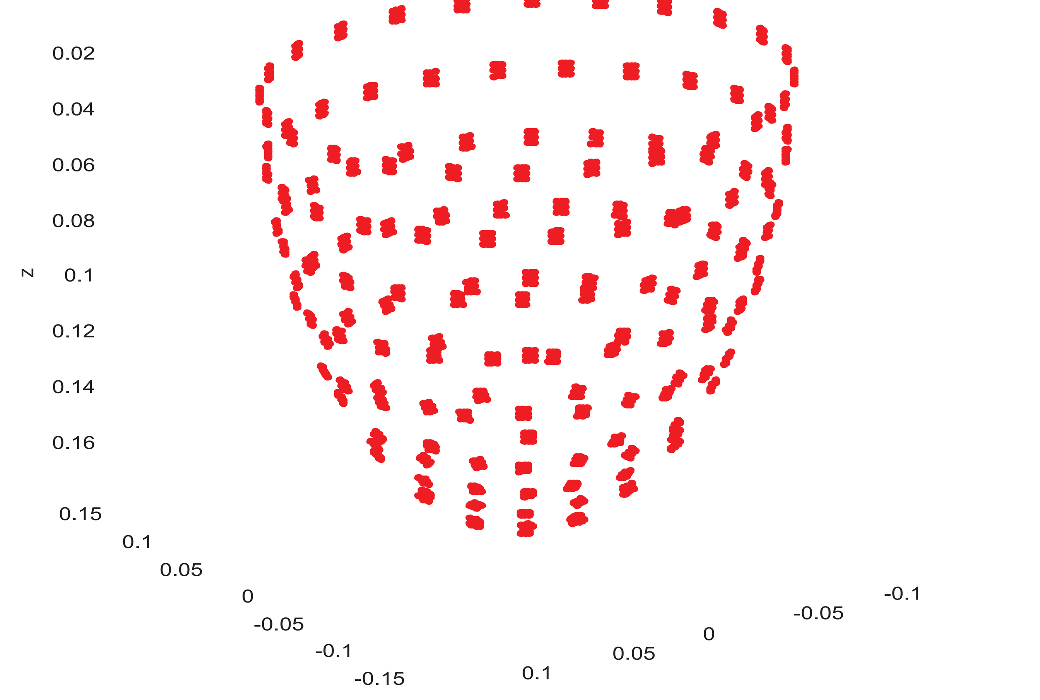

Fig. 2: 3DUSCT II aperture defined by its receiver and emitters, distributed in space around the measurement container.

Motivation and Idea

Imaging can be described in the spatial Fourier domain (k-space) as linear process[4], i.e. as multiplication of the object function with the imaging function given by the aperture. SAFT apertures with significant spatial extend in relation to the object size, especially object enclosing apertures, exaggerate low-frequency components[2]. These overamplified object frequencies are the reason for a blurred characteristic in straight-forward SAFT imaging[5].

Aperture representation in k-space

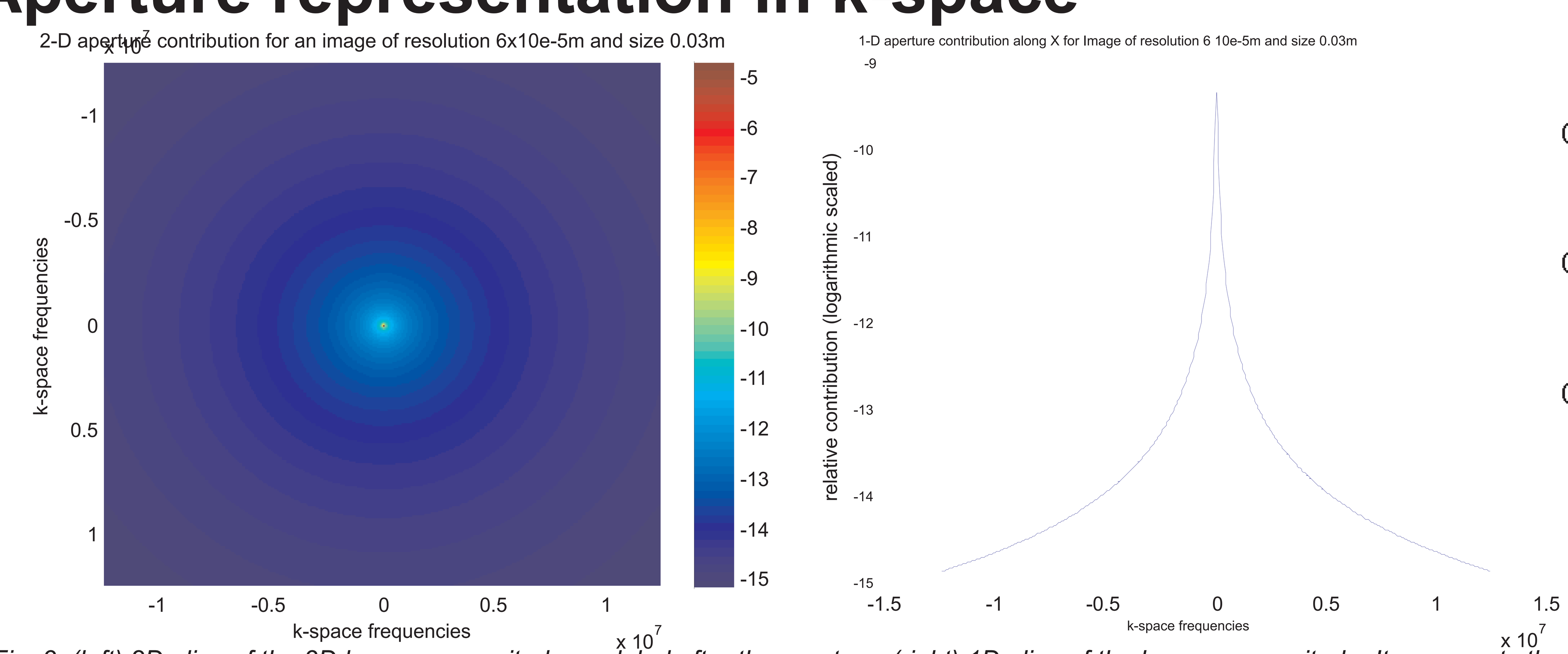

Fig. 3: (left) 2D-slice of the 3D k-space magnitude modeled after the aperture, (right) 1D-slice of the k-space magnitude. It represents the weighting, a spherical aperture applies on the imaged objects.

Methods

The 3DUSCT II aperture was modeled by its spatial position of the transducer elements and the frequency characteristic of the ultrasound transducers (center frequency 2.6MHz and 50% relative bandwidth). As simulated objects perfect point scatterers were chosen as they have a known uniform k-space contribution. A resolution metric was extracted by applying a contour filter and defining the mean full-width-half-maximum (FWHM) as resolution per point scatterer.

The aperture compensation filter, the 'glasses', was applied to the reconstructed images, correcting the image blur introduced by the aperture and imaging process and enhancing the resolution.

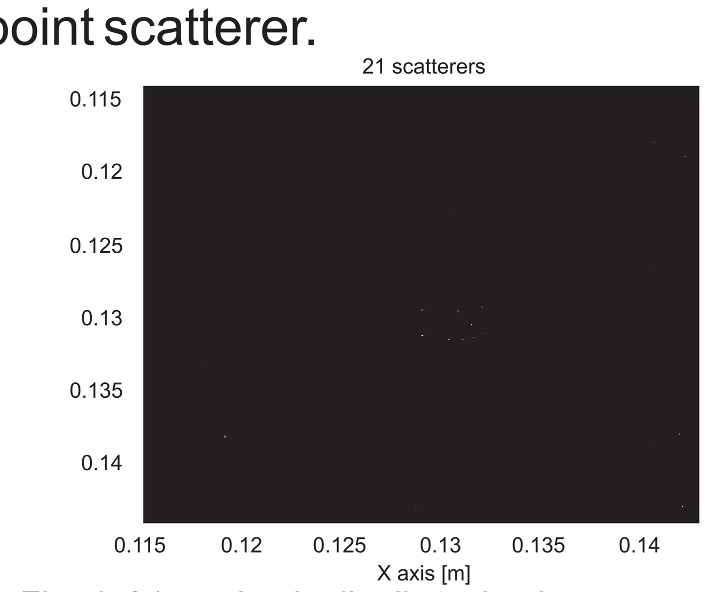

Fig. 4: 21 randomly distributed point scatterers differing in reflectivity used for the imaging.

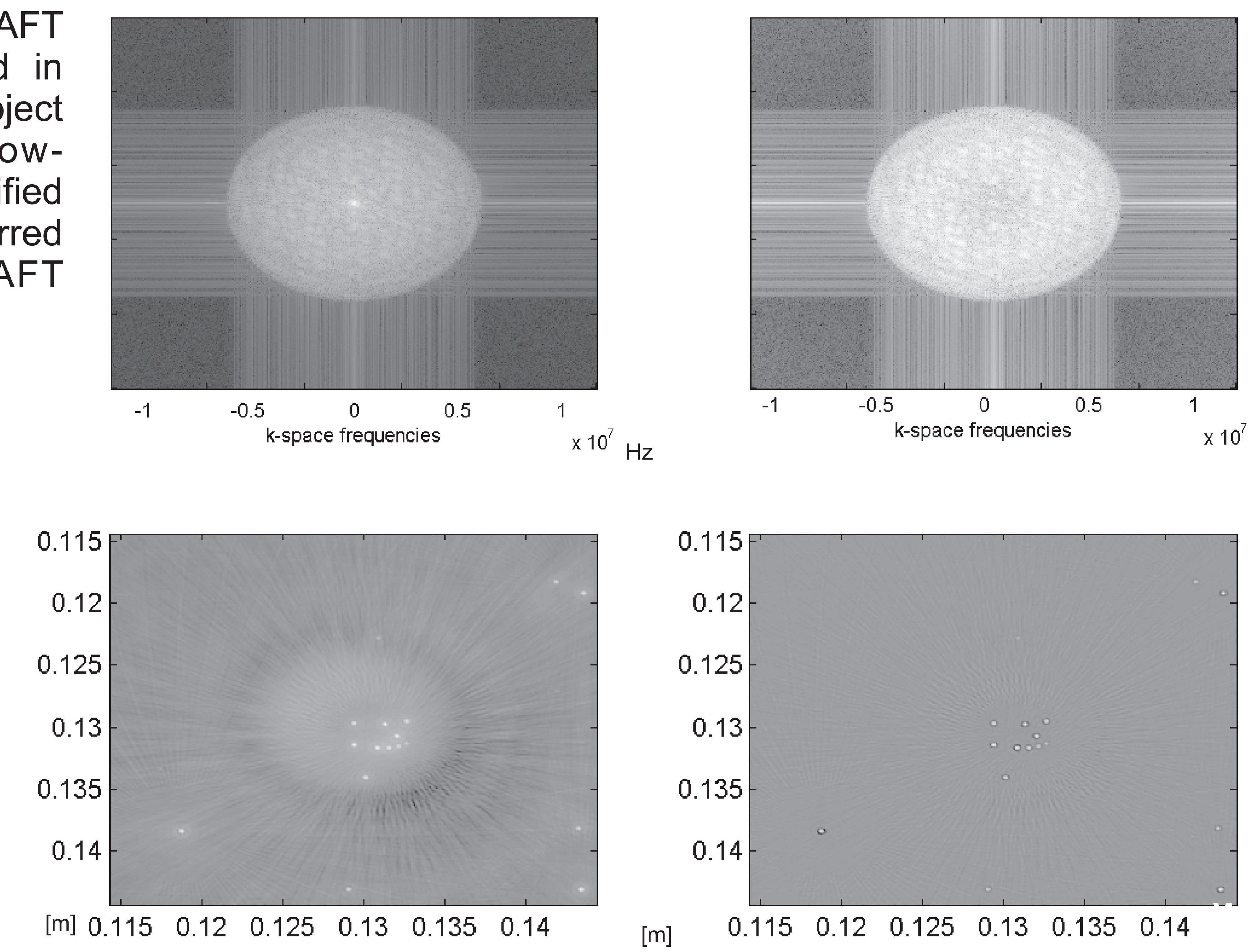

Fig. 5: Reflectivity imaging with simulated data: the top row represents the k-space, bottom row represents the spatial (image) domain. Left column is without aperture compensation filter, right column with applied filter. The image intensity is normalized and logarithmic scaled. In the k-space images the centered disks are defined by the maximum supported frequency of the imaging system. Ideal imaging would happen if the intensity would be the same if the support discs would fill the complete k-space .

Results

21 point scatterer simulation

Imaging metrics	Resolved point scatterers	Mean resolution / in 10^{-4} m	Median resolution / in 10^{-4} m	Std. deviation / in 10^{-4} m
Straight forward SAFT imaging	16	2.52	2.44	2.71
SAFT with aperture compensation	13	1.85	1.85	2.45

Real breast data image

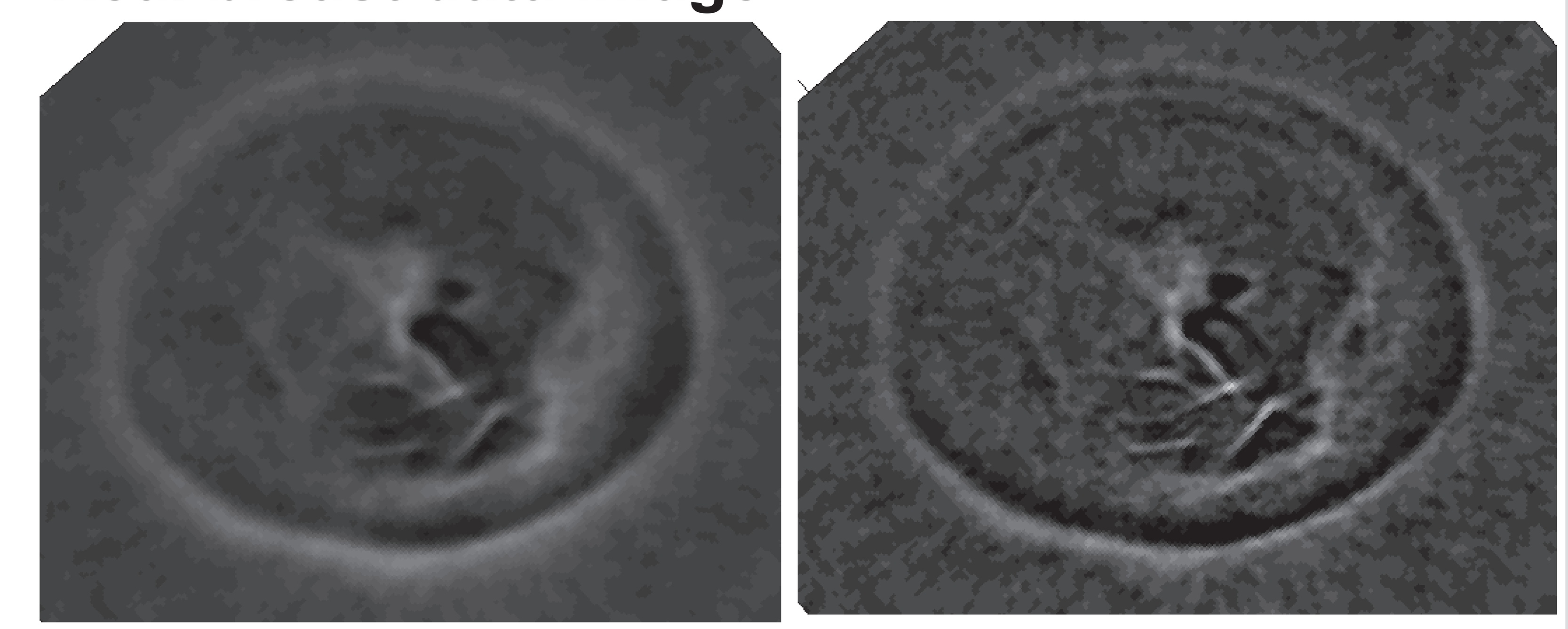

Fig. 6: Comparison of reflectivity breast images without (left) and with (right) aperture compensation. 2D frontal image slice of a breast of a patient from a clinical study at University Hospital Jena in 2012. Image sizes approx. 12cm x 11cm, both images are contrast enhanced for better visability.

Discussion

- An aperture filter was constructed and the performance regarding the resolution was evaluated. A improvement with simulated point scatterers in the mean resolution over straight-forward SAFT by 26% was achieved.
- Also in images created with real world data a sharpening and increase in resolution could be observed. New tissue structures which were before unstructured clouds became visible, also the skin is sharper depicted
- On the down side, the contrast seems to be slightly degraded as high-frequency artifacts, the grating-lobe like SAFT ellipses, are amplified in the imaging, too.

REFERENCES

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[5] M. Zapf, Simulation eines Ultraschalltomographen im k-Space, Master Thesis, University of Applied Science Karlsruhe, 2010