# USCT Data challenge: field report from KIT


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3D Ultrasound Computer Tomography

## Used data sets

- 2D USCT data of Spanish National Research Council (CISC) and the Complutense University of Madrid (UCM)
- 2D USCT data of Technical University of Delft

## Applied algorithms

### Reflectivity tomography

- 3D synthetic aperture focusing technique (SAFT)

$$R(\vec{p}) = \sum_{j,k} T(A_{j,k}(t(\vec{p})))$$

  - $R(\vec{p})$: reconstructed volume at voxel position $\vec{p}$
  - $T(A_{j,k}(t(\vec{p})))$: A-scan $A_{j,k}$ at emitter positon $\vec{e_j}$ and receiver position $\vec{r_k}$ preprocessed with signal processing chain $T$
  - Time $t$ is related to voxel position $\vec{p}$ by

$$t(\vec{p}) = \frac{\|\vec{p} - \vec{e_j}\| + \|\vec{p} - \vec{r_k}\|}{\hat{c}(\vec{p}, \vec{e_j}, \vec{r_k})}$$

  - $\hat{c}(\vec{p}, \vec{e_j}, \vec{r_k})$: harmonic mean of sound speed from $\vec{e_j}$ to $\vec{p}$ and $\vec{p}$ to $\vec{r_k}$.
- Sound speed correction: estimation of $\hat{c}(\vec{p}, \vec{e_j}, \vec{r_k})$ from reconstructed sound speed map
- Preprocessing by matched filter and (optionally) signal detection followed by convolution with optimal pulse [1]
- SAFT implemented on GPU [2][3]

### Transmission tomography

- Straight rays: ignoring refraction, diffraction and scattering
- Time of flight (TOF) and attenuation $a$ detection in A-scans by cross-correlation with empty measurement
- Linear equation system:

$$\vec{b} = \mathbf{A}\vec{u}$$

  - $\vec{b}$: vector of TOFs resp. $a$ detected for all emitter-receiver combinations
  - $\mathbf{A}$: matrix modeling the imaging process
  - $\vec{u}$: vector of reconstructed sound speed image
- Solution for $\vec{u}$ by algebraic reconstruction technique (ART) [4]
- Minimization of total variation (TV) using TVAL3 [5] algorithm
- Regularization controlled by $\beta$ (weight for TV minimization) and $\mu$ (weight for misfit)

## Results I: 2D Delft USCT

- Uncorrected SAFT computed in approx. 8 s (Figure 1)

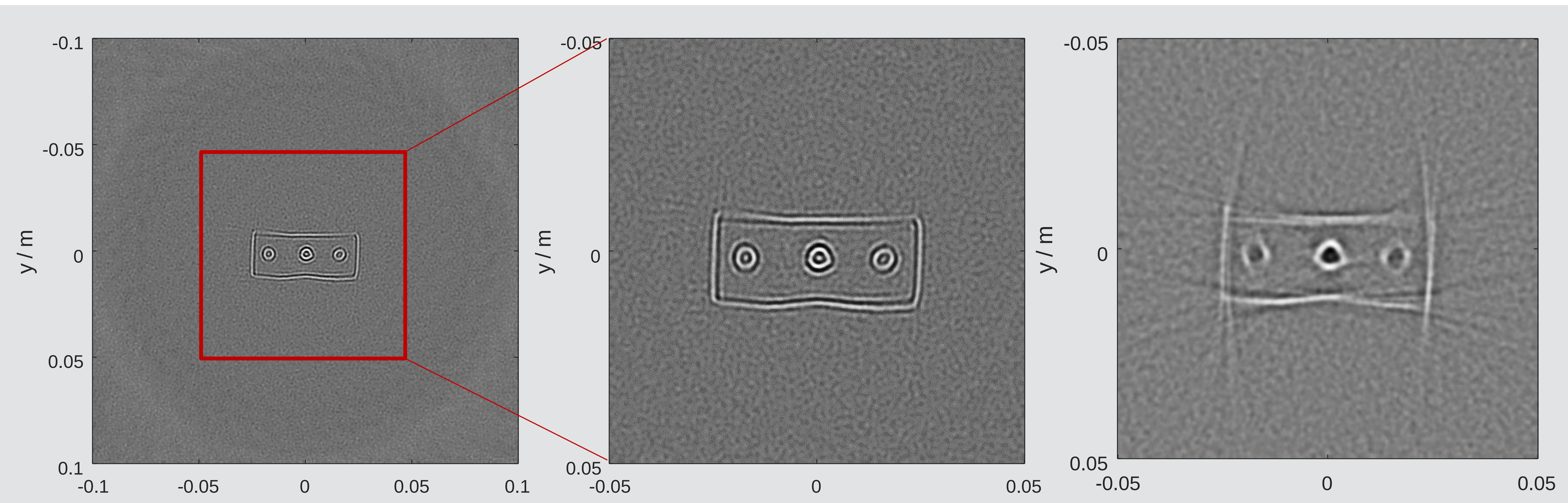


***Figure 1:** Reflectivity reconstruction with uncorrected SAFT using the original RF data after matched filtering (left). Detail view of the same configuration (middle). Reconstruction using convolution with optimal pulse of width 1.2 mm (right).*

- Sound speed reconstruction with ART was not able to recover the 2D Delft USCT phantom

## Results II: 2D CISC/UCM

- Reflectivity reconstruction with uncorrected and sound speed corrected SAFT (Figure 2, Figure 3)
- Computation time: approx. 180 s, theoretically approx. 5 s

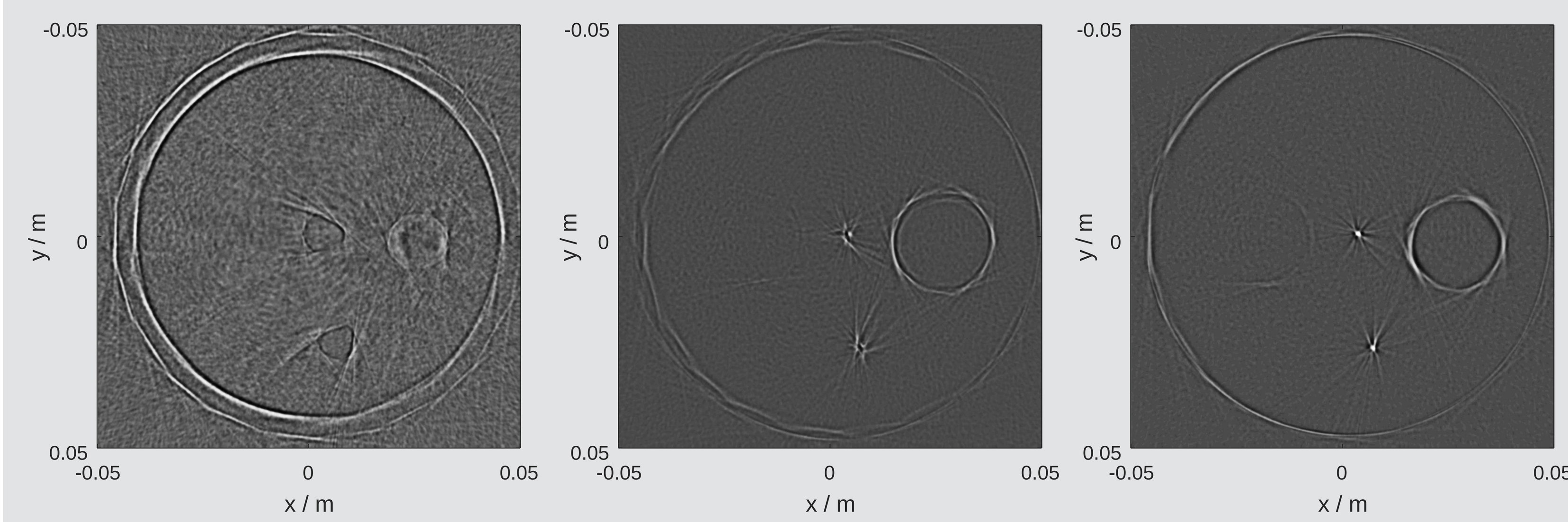


***Figure 2:** Reflectivity reconstruction with uncorrected SAFT using optimal pulse of width 0.48 mm (left). Sound speed corrected SAFT with ART-reconstructed sound speed map (middle). Sound speed corrected SAFT with artificial sound speed map based on data challenge phantom description and estimated sound speed values (right).*

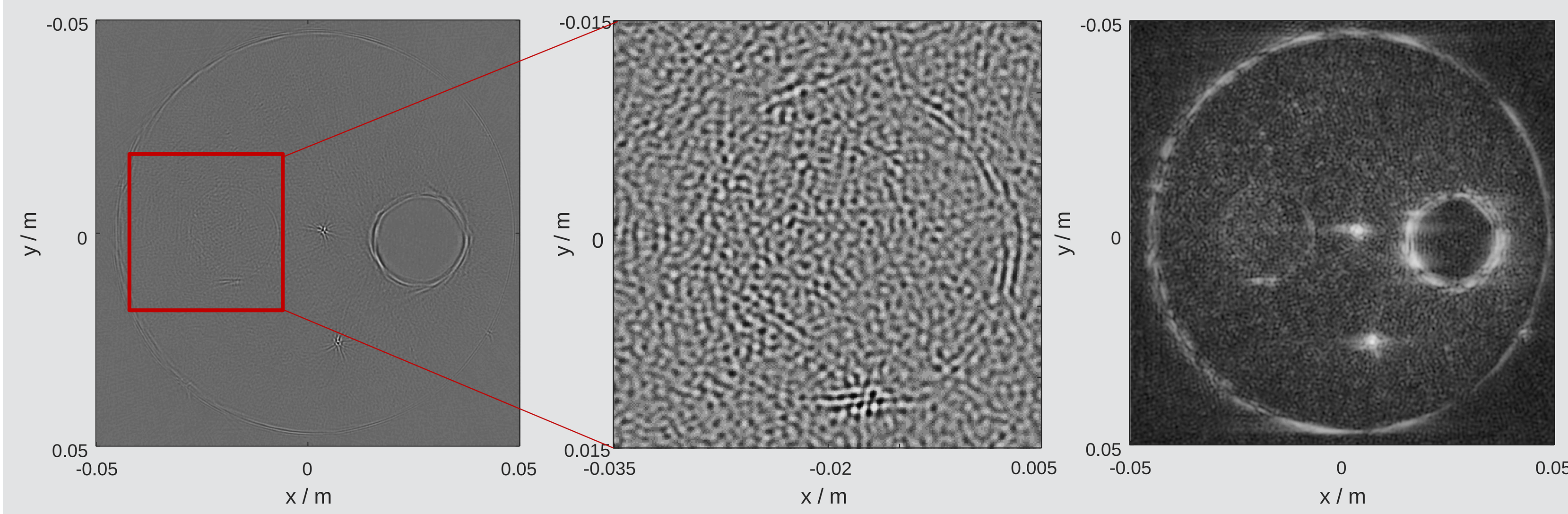


***Figure 3:** Reflectivity reconstruction with matched filtered RF data SAFT (left). Detail view (middle). Image filtered additionally with a 2D envelope filter and given in logarithmic scale to linearize the contrast (right).*

- Sound speed reconstruction using ART (Figure 4)

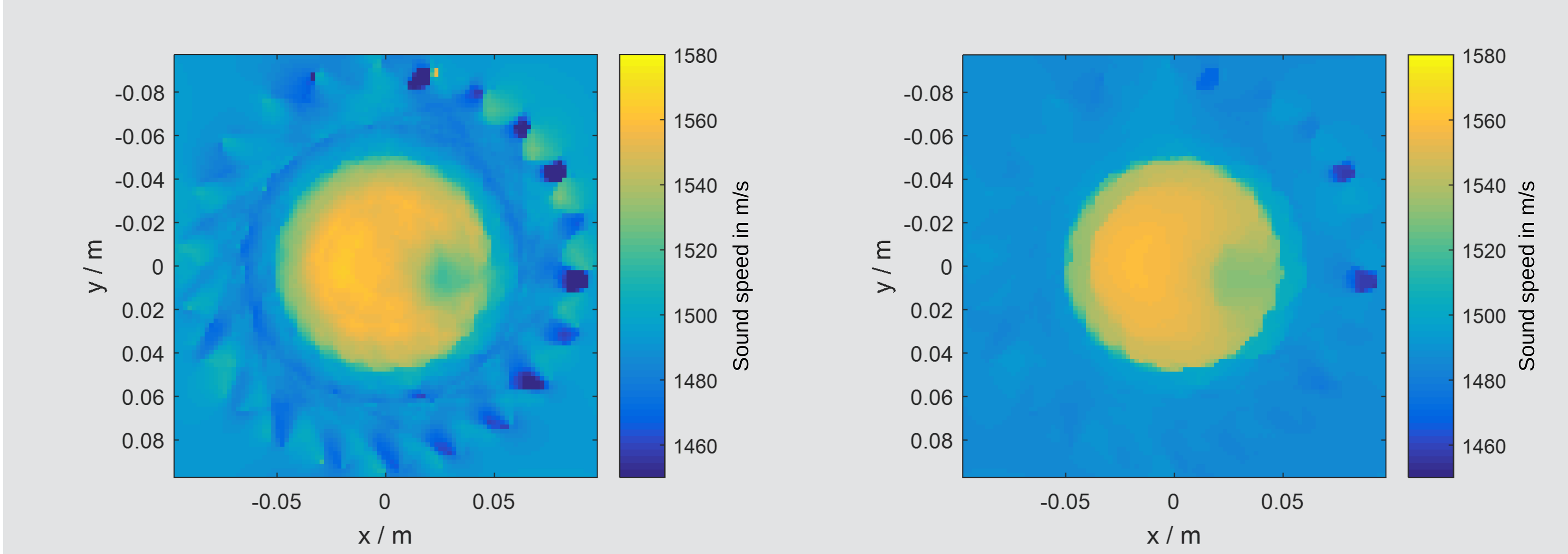


***Figure 4:** Sound speed reconstruction with ART and different regularization parameters: μ=200, β=20 (left) and μ=100, β=100 (right).*

- Attenuation reconstruction using ART (Figure 5)

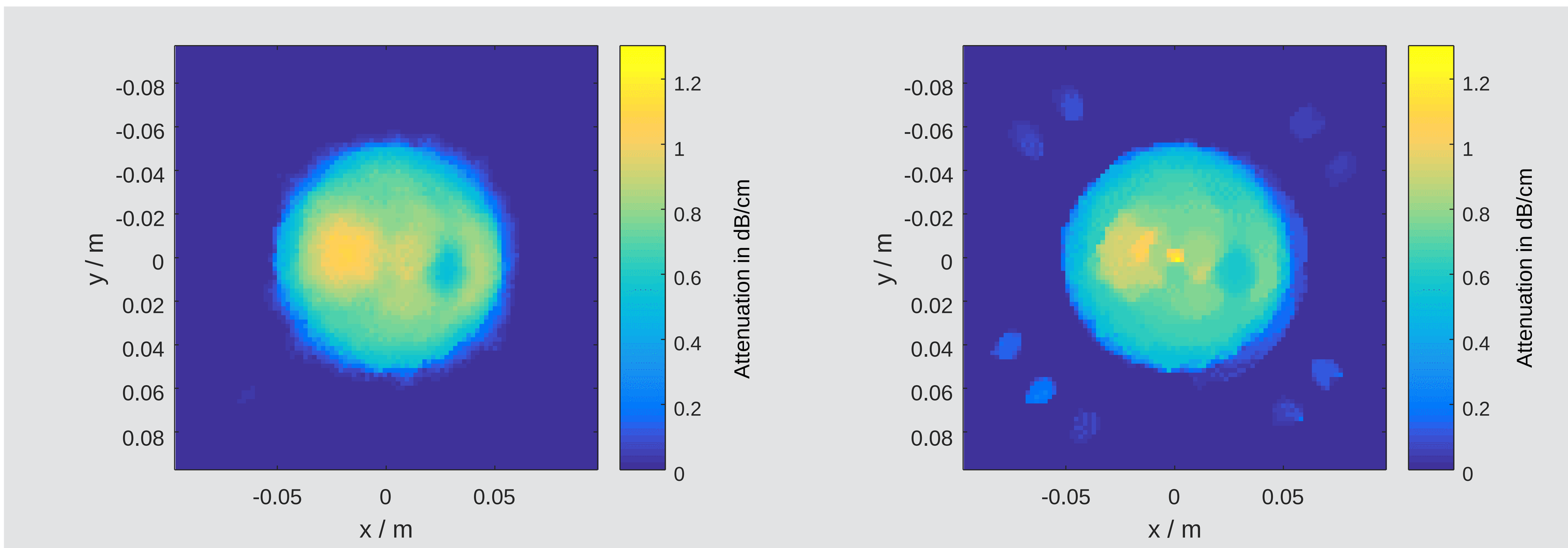


***Figure 5:** Attenuation reconstruction with ART and different regularization parameters: μ=20, β=10 (left) and μ=20, β=100 (right).*

## Conclusion

- Successful application of algorithms to all provided data sets
- We were able to adapt our algorithms to the provided challenge signal data in less than one day.


*References:*

[1] N.V. Ruiter et al. "Improvement of 3D ultrasound computer tomography images by signal pre-processing", Proc. IEEE UFFC Symposium, 2008

[2] E. Kretzek et al. "GPU based 3D SAFT reconstruction including phase aberration", Proc. SPIE MI, 2014

[3] E. Kretzek et al. "GPU-based 3D SAFT reconstruction including attenuation correction", Proc. SPIE MI, 2015

[4] M. Birk et al. "GPU-based iterative transmission reconstruction in 3D Ultrasound Computer Tomography", Journal of Parallel and Distributed Computing 74(1), pp. 1730-1743, 2014

[5] C. Li, "Compressive Sensing for 3D Data Processing Tasks: Applications, Models and Algorithms", Phd Thesis, Rice University Texas, 2011