Towards 4D Interventional Guidance: Reconstructing Interventional Tools From Four X-Ray Projections using a Deep Neural Network

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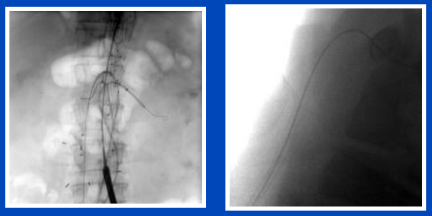
Motivation

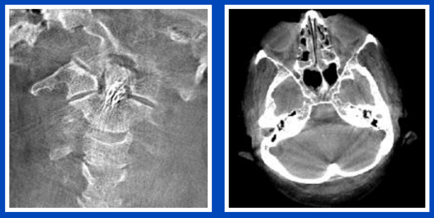
Today's Interventional guidance (IG)

C-arm systems



Fluoroscopy (2D + time)

➤ limited information about 3D structure of interventional tools (e.g. of stents)



Tomography (3D)

➤ no temporal information

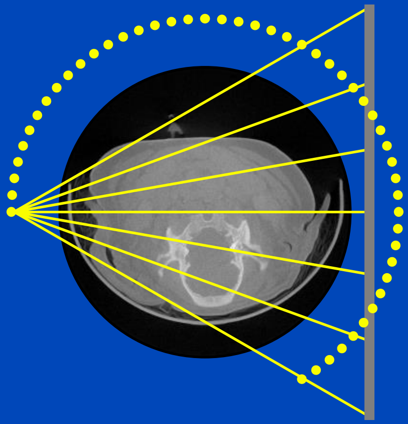
Tomographic (4D) interventional guidance

- could provide full spatiotemporal information about interventional tools
- could enable new minimally invasive radiological interventions

Currently, tomographic interventional guidance would result in excessively high dose due to the need for continuous CBCT scanning.

Prior Work

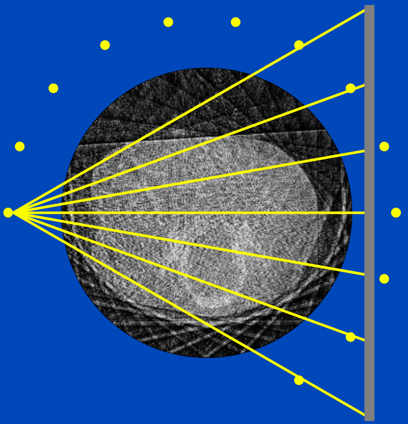
Prior work[1] showed feasibility of reconstructing interventional tools from 16 projections if patient prior is available. Has been further improved to account for patient motion via registration of the prior scan[2].



Drawbacks of resulting pipeline

- Dose ~16 times higher than for standard fluoroscopic IG
- Registration[2] of prior scan is too computing-intensive to realize the pipeline in real-time

➤ clinically impractical



Develop a novel deep learning-based pipeline

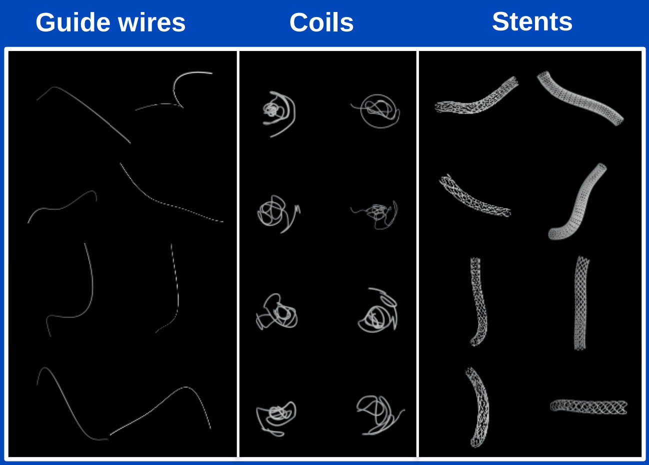
- **Deep Tool Extraction (DTE)**
  Extract the interventional tools in the projection domain
- **Deep Tool Reconstruction (DTR)**
  Segment interventional tools in reconstructions in sparsely reconstructed volumes

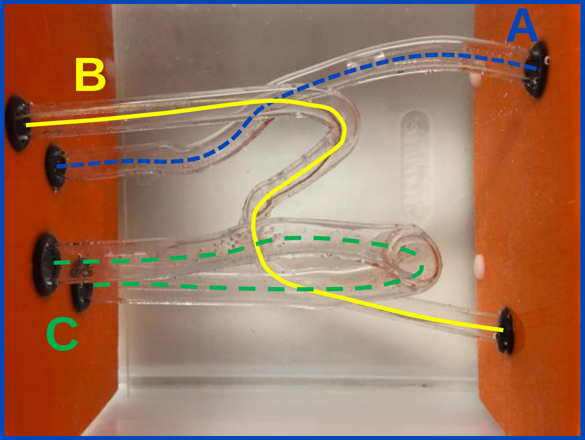
[1] J. Kuntz, M. Kachelrieß, et al., "Real-time x-ray-based 4D image guidance […]", Eur. Radiol., Jun. 2013.
[2] B. Flach, M. Kachelrieß, et al., "Low dose tomographic fluoroscopy: 4D intervention […].", Med. Phys., Oct 2013.

Simulations & Measurements

Simulations

- Generated 3D models of guide wires, stents and coils of random deformations, diameters and shape matching those parameters of commercially available tools
- Simulated in a C-arm Cone-Beam CT (CBCT) geometry to generate projection data and reconstructions



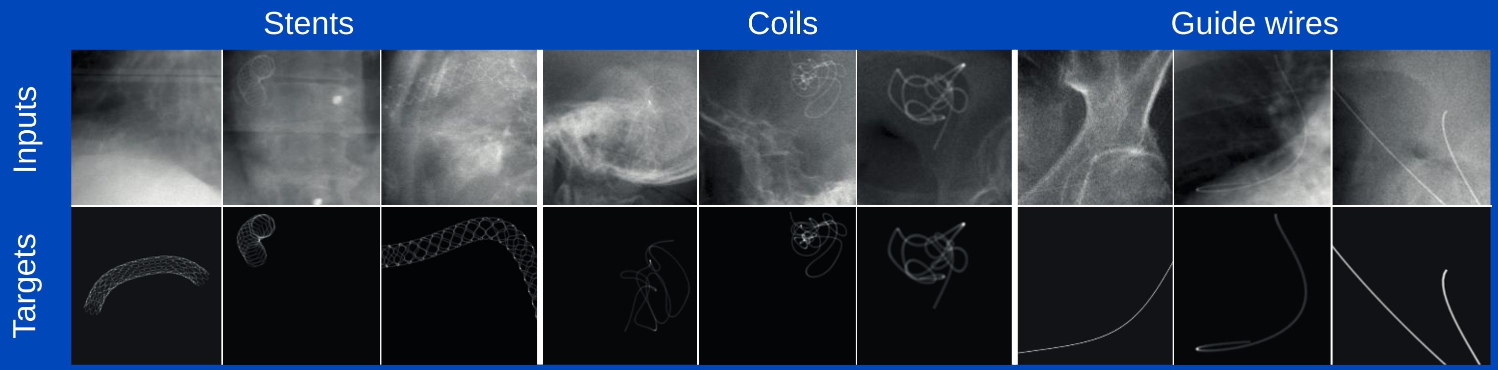


Measurements

- We scanned commercially available stents, guide wires and coils to test our method using both a custom intervention phantom and a commercial brain vessel phantom
- The projections of these scans were superimposed on projections of CBCT patient scans

Deep Tool Extraction

- The CNN (U-net) is trained to extract interventional tools from projections
- During training we add forward projections of 3D models on randomly cropped patches of patient scans
- Tools-only projections serve as ground truth
- To reduce amount of training data where interventional tools are outside patient reject Ps with $\mathrm{mean}(P) \leq 1$.
- Data augmentation include
  - Random flipping of the tools horizontally
  - Additive Poisson noise
  - Multivariate Gaussian blurring
- During training we minimize the L_1-loss using the Adam optimizer

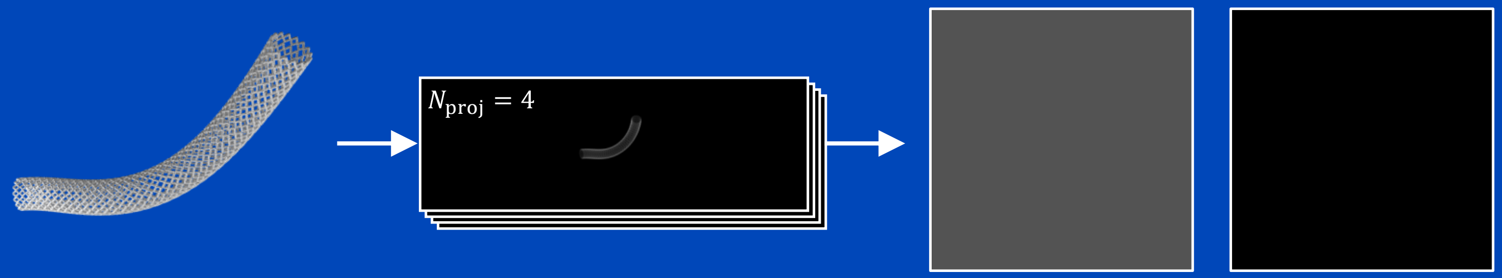


Deep Tool Reconstruction

- The CNN (U-net) segments interventional tools, that were sparsely FDK reconstructed from four x-ray projections
- It uses 13 consecutive slices (corresponding to 1.3 mm) as input to leverage 3D information
- Voxel representations of centered slices serve as ground truth
- During training we minimize the soft Dice loss with Laplace smoothing between network output y and ground truth $\hat{y}$

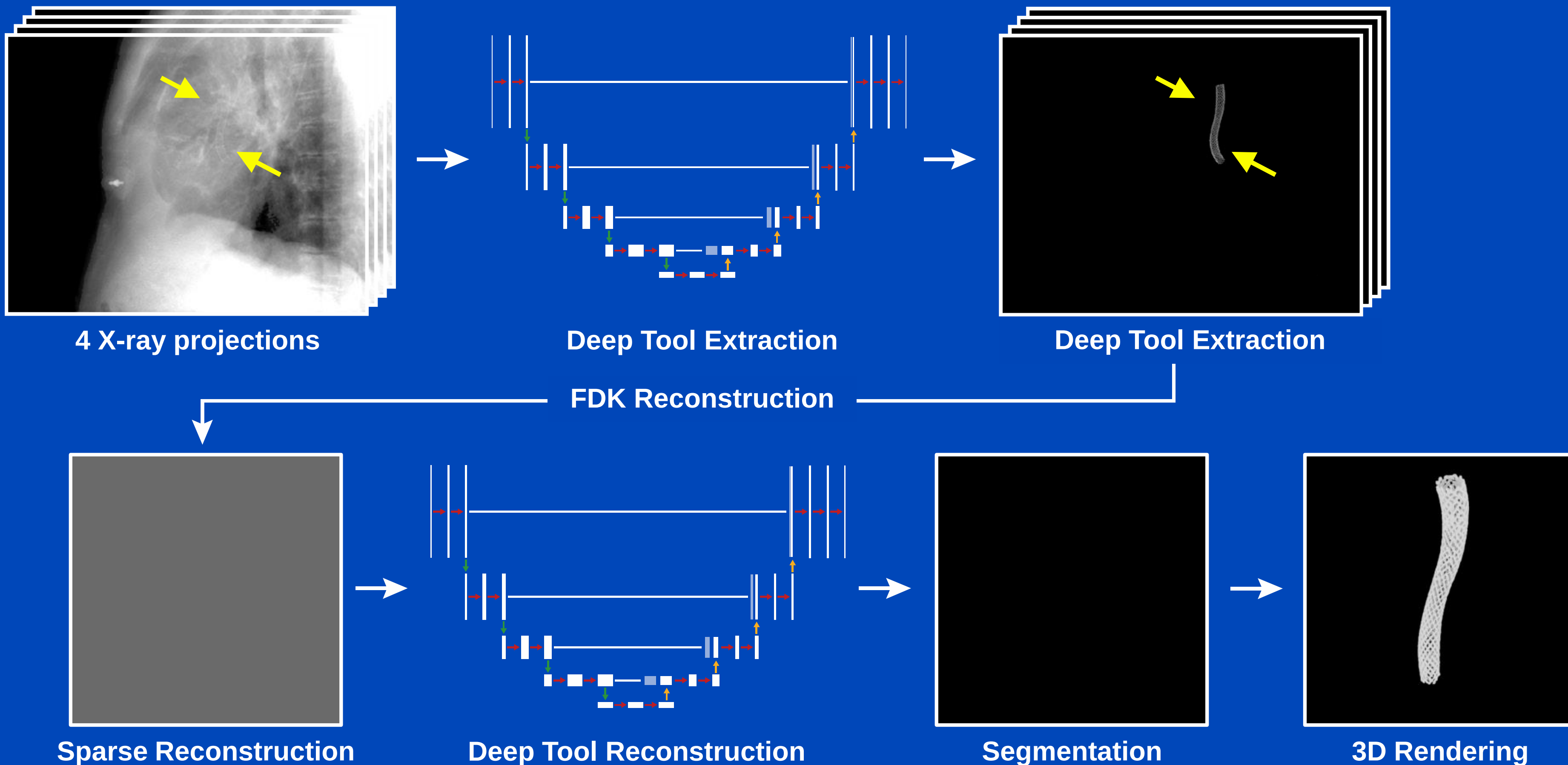
$$L_{\mathrm{SD}}(y,\hat{y}) = 1 - \frac{2\sum_k y_k \hat{y}_k + 1}{\sum_k y_k + \sum_k \hat{y}_k + 1}$$

using the Adam optimizer.

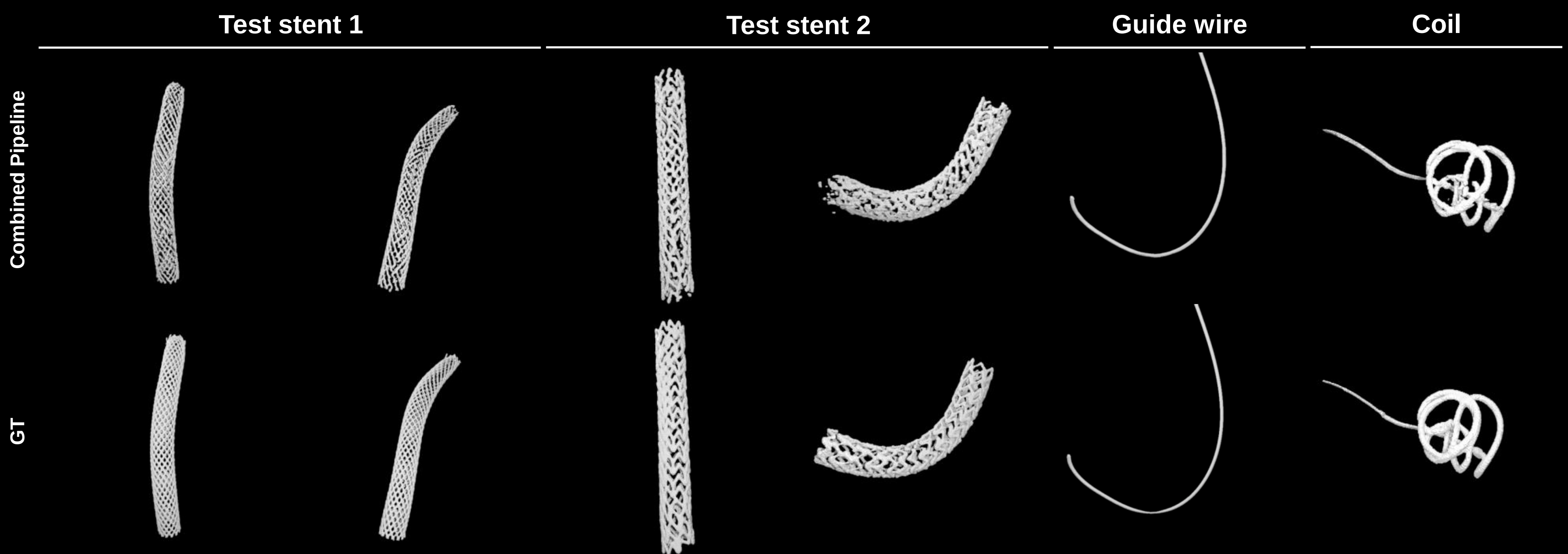


3D models | Simulated forward projections | Reconstruction | GT segmentation

Combined Pipeline



Results
Combined Pipeline



Conclusion & Outlook

Deep Tool Extraction

- eliminates the need for a prior scan and registration step
  - ➤ This eases clinical workflow
  - ➤ No problems with patient motion
  - ➤ Complete pipeline is applicable in real time

Deep Tool Reconstruction

- can reconstruct interventional tools from only 4 x-ray projections with high accuracy
- currently limited to the case were the tool doesn’t move between the four projections

Future work comprises

- investigating the performance for a combination of tools (e.g. stents around guide wire)
- testing the pipeline on clinical data

Thank You!

This presentation will soon be available at www.dkfz.de/ct.
We are hiring for this and similar topics! Contact: marc.kachelriess@dkfz.de.
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.