Running Prior for Patient Motion Correction in Low-Dose 3D+Time Interventional Flat Detector CT

Barbara Flach[1,2], Jan Kuntz[2], Marcus Brehm[1,2], Sönke Bartling[2,3], Marc Kachelrieß[1,2]

[1] Institute of Medical Physics, University of Erlangen-Nürnberg, Germany

[2] Medical Physics in Radiology, German Cancer Research Center, Heidelberg, Germany

[3] Institute for Clinical Radiology and Nuclear Medicine, University Medical Center Mannheim, Germany

Purpose:

4D (=3D+time) interventional image guidance requires tomographic data acquisition during the whole intervention. However, the method, which is also called tomographic fluoroscopy or CT fluoroscopy, will be routinely accepted only if the patient dose level can be kept as low as in 2D+time fluoroscopic guidance, which is the standard image guidance technique in today's interventions. To achieve this goal of enabling tomographic fluoroscopy at the same dose as projective fluoroscopy the update volumes have to be reconstructed from data with very sparse angular sampling at a very low dose. To guarantee high quality of the update volumes during intervention a high quality prior volume acquired before intervention is necessary [1]. Depending on the type and duration of an intervention patient motion can lead to non-applicability of the static prior volume. Consequently, the prior volume needs to be continuously updated.

Materials and Methods:

We propose a running prior that adapts itself by the combination of the two concepts, registration and substitution. In the registration step a combination of affine registration (based on mutual information [2]) and deformable registration [3] adapts the prior to a target prior which shows the current situation by reconstructing the latest 120 projections (corresponds to about four scanner rotations with sparse sampling). In the substitution step a forward projection of the deformed prior yields virtual rawdata that are densely sampled in the angular direction (600 projections, same number of projections as for the static prior). The projections measured for the current update (in our case 15 projections) are used to substitute the corresponding virtual projections. A reconstruction of these substituted data yields the running prior.

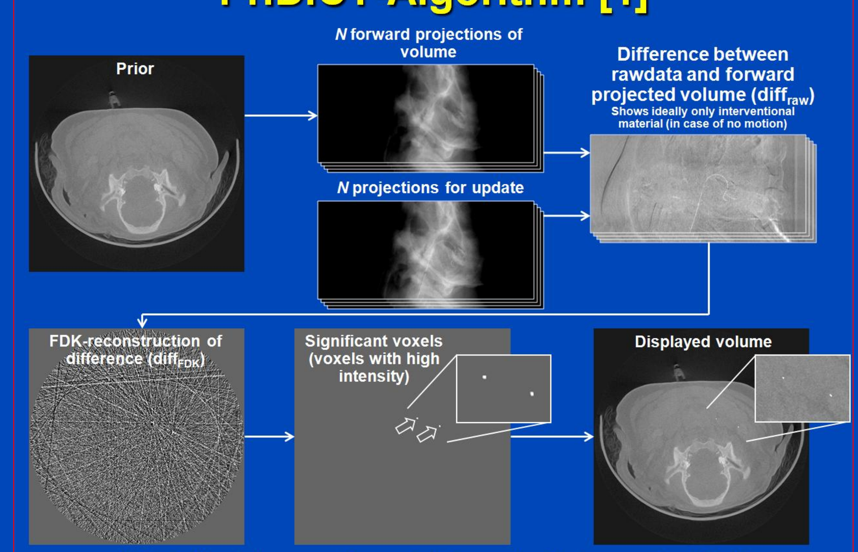
For the evaluation of the method we used an in vivo head scan of a pig acquired by a prototype volume CT system since no dedicated 3D+temporal interventional CT system exists nowadays. This CT system consists of a flat detector mounted on a continuously rotating clinical CT gantry.

Purpose

- 4D (= 3D+T) reconstruction for interventional guidance at dose level as low as in 2D+T-fluoroscopy
  - Display interventional material like guidewire or stents (high contrast objects) in the surrounding tissue temporally resolved
- State-of-the-Art: PrIDICT-algorithm [1]
  - Uses information of a high quality prior acquired before intervention to reconstruct high quality update volumes from very few projections at very low dose
- Problem: Patient motion during the intervention

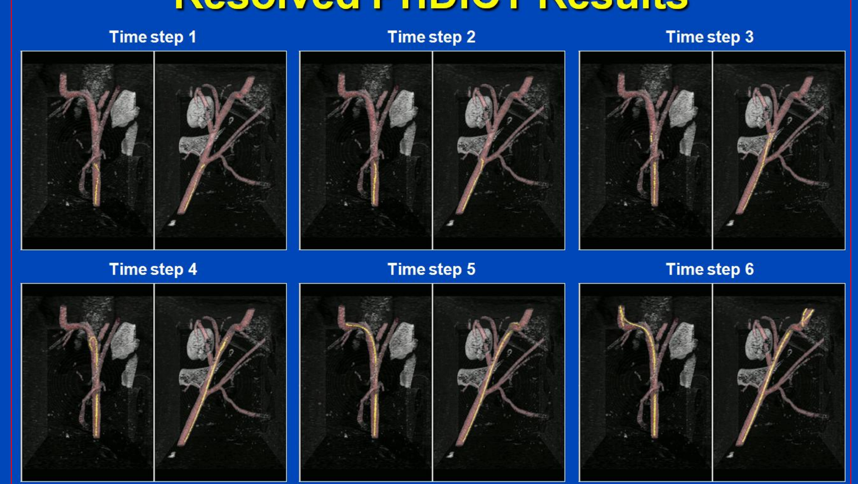
Aim: Allow for patient motion by updating prior continuously such that it fits the current situation – for dose reasons without additional projections
- Deformation via registration
- Involving current projections (necessary for new low contrast objects)

PrIDICT-Algorithm [1]



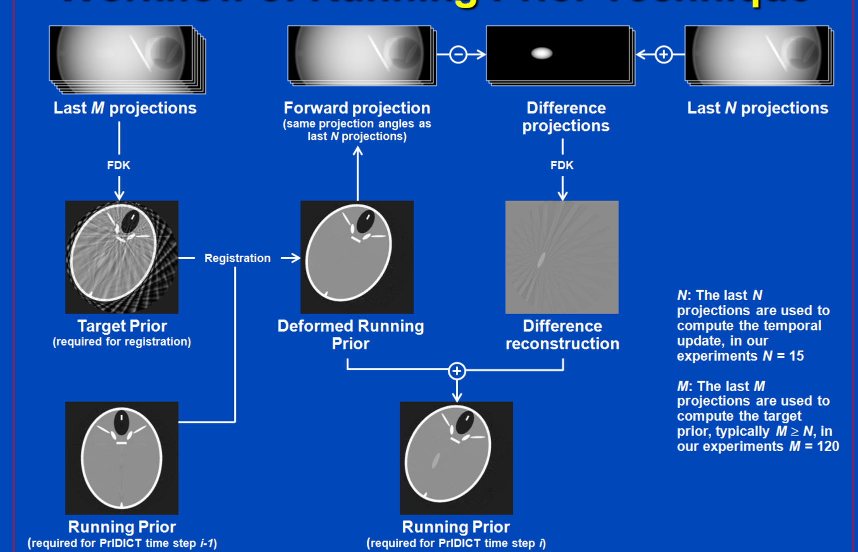
N: The last N projections are used to compute the temporal update, in our experiments N = 15

Volume Rendering of Temporally Resolved PrIDICT Results



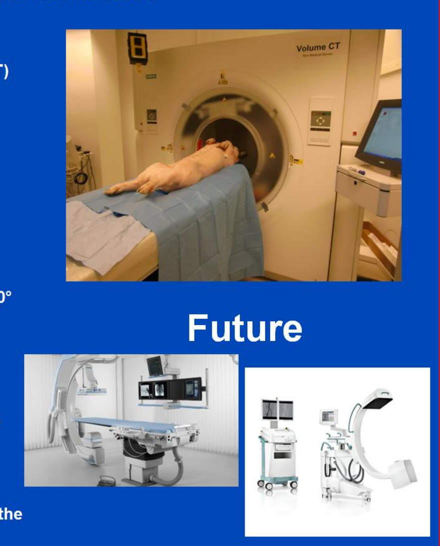
Intervention: Inserting a guide wire in the pig's carotid

Workflow of Running Prior Technique

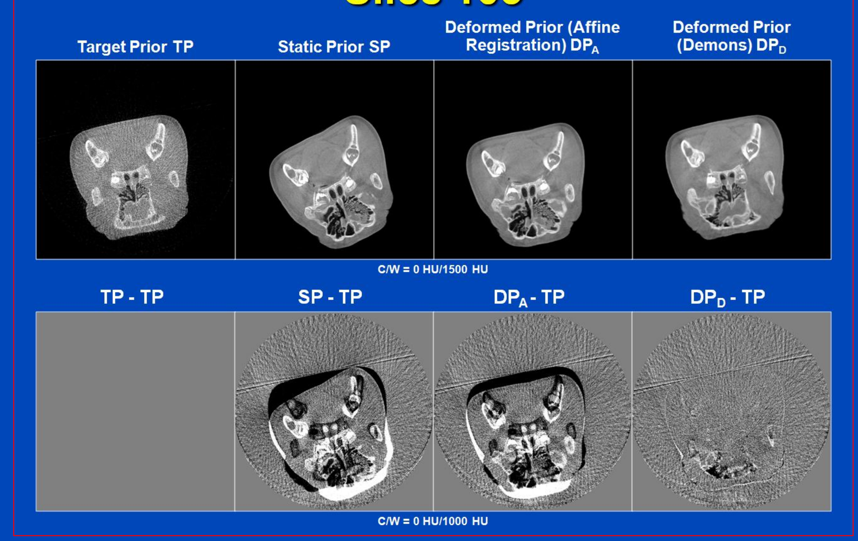


Measurement

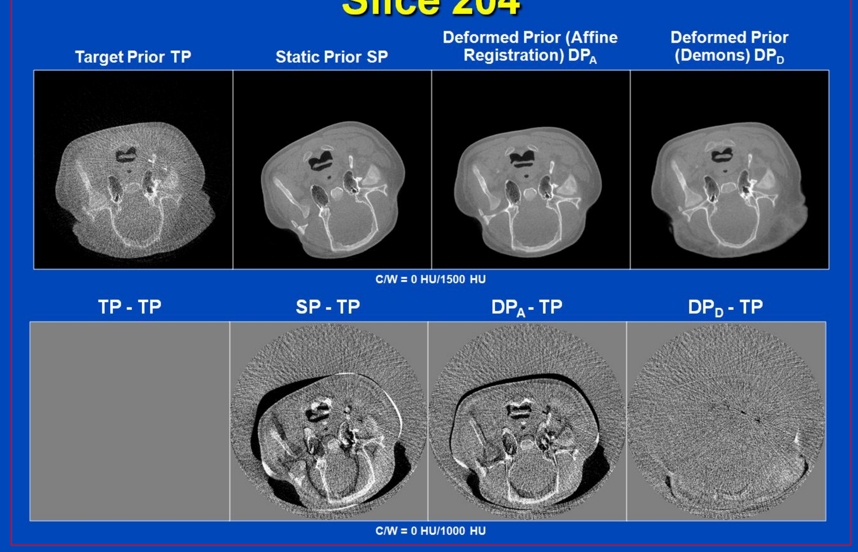
- System:
  - Flat detector CT prototype based on a clinical CT gantry (Siemens Volume CT)
  - Tube voltage: 80 kV
  - Tube current: 50 mA
- Patient:
  - Pig in-vivo
  - Moved manually between prior and intervention scan
- Prior scan:
  - Before intervention
  - N_{360} = 600 std. dose projections per 360°
  - T_{rot} = 19 s
  - 1 single rotation
- Intervention scan:
  - During intervention
  - N_{360} = 30 low dose projections per 360°
  - T_{rot} = 4 s
  - Many rotations (depending on time needed for intervention)
  - Guide wire inserted into the carotid of the pig's head during the scan



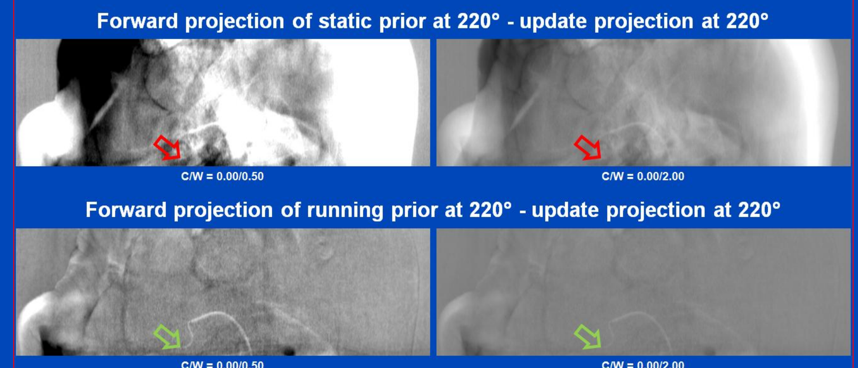
Motion Correction by Registration – Slice 103



Motion Correction by Registration – Slice 204

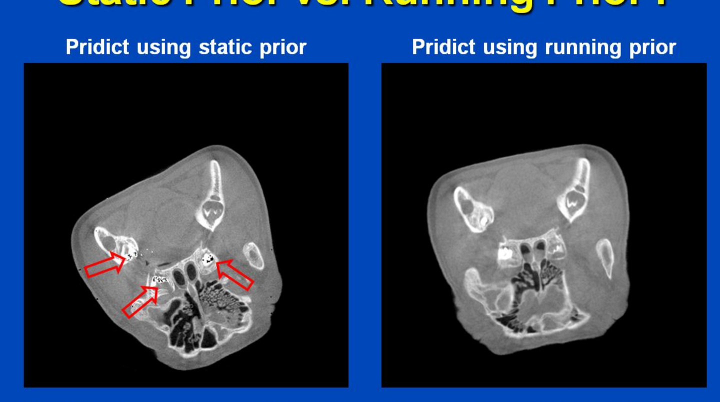


Improvement in Rawdata Difference $diff_{raw}$



The rawdata difference using the static prior is disturbed by differences resulting from motion while the rawdata difference using the running prior shows almost only interventional material. Especially the tip of the guide wire is only visible when using the running prior.

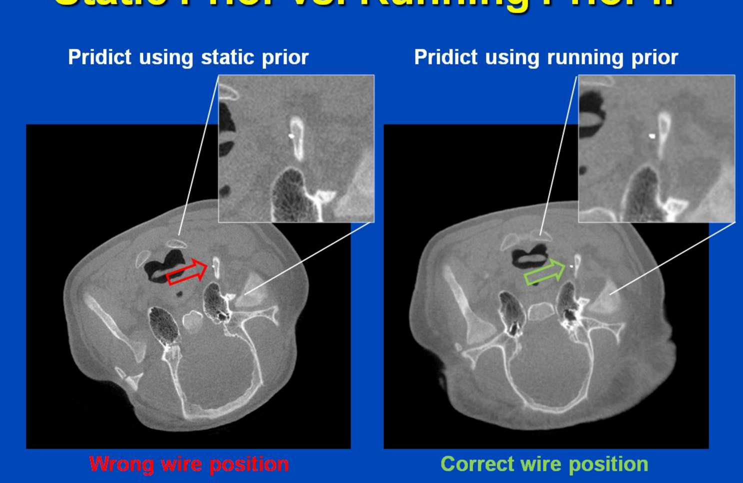
Static Prior vs. Running Prior I



With the static prior many wrong voxels are recognized as significant because of the motion between prior scan and intervention scan. With the running prior technique this is compensated within the registration step.

C/W = 0 HU/1500 HU

Static Prior vs. Running Prior II



C/W = 0 HU/1500 HU

References:

[1] J. Kuntz, S. Bartling, S. Schönberg, R. Gupta, W. Semmler and M. Kachelrieß. "Time-resolved X-ray based 4D image guidance of minimally-invasive interventions". Manuscript submitted for publication.

[2] P. Viola, and W.I. Wells. "Alignment by Maximization of Mutual Information". International Journal of Computer Vision. 24(2): 137-154. 1997

[3] J.-P. Thirion. "Image matching as a diffusion process: an analogy with Maxwell's demons". Medical Image Analysis. 2(3): 243-260. 1998

Results:

By the running prior technique it is possible to correct for motion of the pig's head up to 30 mm between the prior scan and the intervention scan. In addition the proposed method works in case of motion during the intervention scan of up to 0.15 mm/s. The resulting running prior images are of high image quality without introducing new artifacts. Hence in the difference between forward projected running prior and the rawdata of the current update only interventional material and almost no discrepancies resulting from patient motion are visible. In consequence the temporal updates show less inconsistency artifacts when using the running prior compared to using the static prior image. Even if image quality is not disturbed using the static prior it is not possible to display the correct position of the interventional material after patient motion which in contrast is no problem when using the running prior technique. By incorporating the latest projections into the prior via replacement we assure that low contrast objects not present during prior scan but during intervention scan appear in the running prior image.

Conclusion:

We conclude that the running prior technique is equivalent to the static prior in case of no patient motion and superior in case of motion. The temporal updates show less artifacts when using the running prior technique. This is reached without additional patient dose because no additional projections need to be acquired. In case of motion the reconstruction of the temporal updates only makes sense using the new proposed method.

Acknowledgement:

This study was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant KA 1678/6-1.

The high performance compute hardware was provided by the Universitätsbund Erlangen-Nürnberg e.V., Erlangen, Germany.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.

Send correspondance requests to:
Barbara Flach
Institute of Medical Physics
University of Erlangen-Nürnberg
Henkestr. 91, 91052 Erlangen, Germany
barbara.flach@imp.uni-erlangen.de