

Boosting Image Quality in Low-Dose RC-Gated 5D Cone-Beam Micro-CT

Stefan Sawall¹, Frank Bergner¹, Robert Lapp², Markus Mronz²,
Marek Karolczak¹, Andreas Hess³, Willi A. Kalender¹, and Marc Kachelrieß¹

¹Institute of Medical Physics, University of Erlangen-Nürnberg, Germany — ²CT Imaging GmbH, Erlangen, Germany — ³Lehrstuhl für Pharmakologie und Toxikologie, University of Erlangen-Nürnberg

Purpose:

Double-gated in-vivo small animal cone-beam micro-CT scans provide five-dimensional information about the object: the three volume dimensions plus the temporal dimensions of the respiratory motion and the heart motion (RC-gating). Double gating is typically performed to separate respiratory from cardiac motion when imaging the animal's lung or heart. [1] We are aiming at significantly improving the image quality achievable in low-dose micro-CT scans of small specimen. On the one hand we want to reduce streak artifacts that result from sparse angular sampling and on the other hand we want to reduce image noise resulting from the small amount of photons available in a given combination of respiratory and cardiac phase.

Materials and Methods:

To correlate our reconstruction with the motion phases of the animal heart and lung we detect the corresponding synchronization information directly from the rawdata (kymogram) [2].

To perform respiratory and cardiac-correlated image reconstruction we use a phase-correlated (PC) Feldkamp algorithm that filters and backprojects only those projections that lie in the desired cardiac and respiratory temporal window. Since only few projections fall into the desired temporal window, streak artifacts may occur unless a very large number of projections at very fine angular increments is acquired. A generalization of the McKinnon-Bates (MKB) algorithm [3] is used to address this issue. It works as follows. First, a standard reconstruction is performed to obtain a prior image. This prior image is blurry in those regions where motion is present, and it is of high image quality elsewhere. Then, a forward projection of the prior image is performed and subtracted from the measured rawdata. These subtracted data are then used for a phase-correlated reconstruction which is added to the prior image.

To reduce noise we apply edge-preserving anisotropic diffusion filters in up to five dimensions during the reconstruction process. The final volume is the low-dose phase-correlated (LDPC) volume.

Measurements were carried out with the dual-source cone-beam micro-CT scanner TomoScape Synergy Twin (CT Imaging GmbH, Erlangen, Germany).

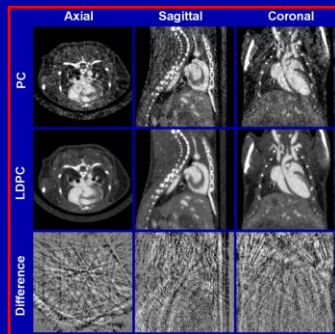


Figure 1: Comparison between conventional phase-correlated reconstruction (respiratory and cardiac gating) and our new iterative low-dose phase-correlated method LDPC. The difference image shows no object structures which indicates that the new method does not result in a reduction of temporal resolution. Noise was reduced from 175 HU to 30 HU. Respiratory phase $r = 0\%$, cardiac phase $c = 80\%$. (300 HU / 400 HU)

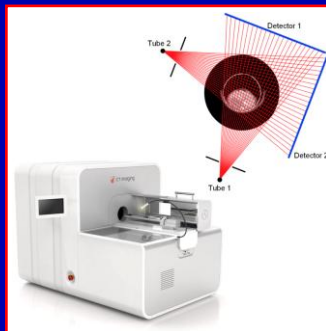


Figure 2: The TomoScape Synergy Twin scanner and a visualization of its cone-beam geometry. The system is a dedicated in-vivo small animal imaging dual source cone-beam CT scanner with a rotation time of 4 s or more. Its spatial resolution lies in the order of $80 \mu\text{m}$. Its temporal resolution in a non-gated mode is 1 s because 30° rotation are sufficient to collect tomographic data. The scanner is able to acquire dual energy CT data.

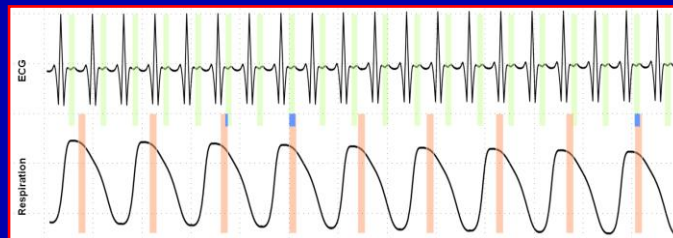


Figure 3: The reconstruction of double-gated volumes uses only the projections (blue) that lie in the desired cardiac (green) and respiratory (red) phase windows.

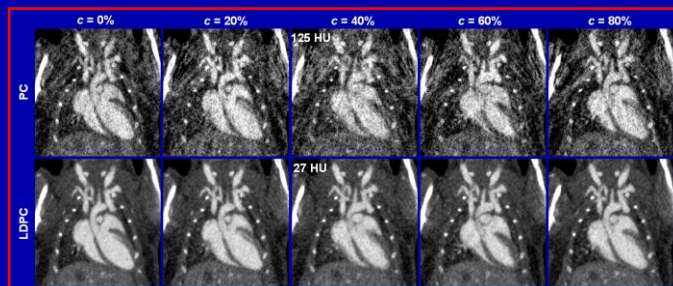


Figure 4: Loop over several cardiac phases at $r = 0\%$. (300 HU / 350 HU)

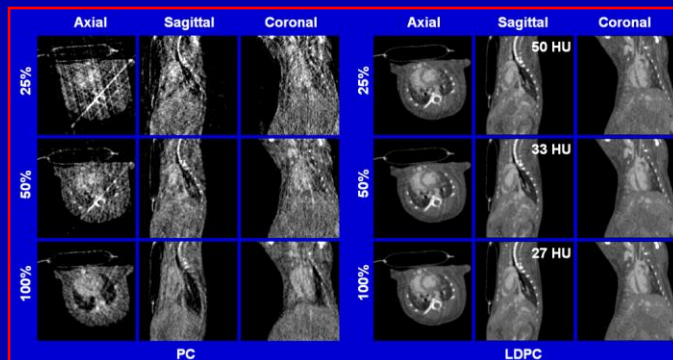


Figure 5: Phase-correlated reconstructions of another mouse centered at $r = 60\%$ and $c = 0\%$ with window widths $\Delta r = 10\%$ and $\Delta c = 20\%$. The left panel shows the conventional phase-correlated reconstructions while the right panel is the proposed low dose approach. Dose levels ranging from 25% to 100% were obtained by using only fractions of the data available. (300 HU / 700 HU)

Results:

The LDPC reconstruction method is evaluated using contrast-enhanced, retrospectively gated micro-CT scans of mice. A typical scan comprises 7200 projections acquired within 10 rotations over 5 minutes at a tube voltage of 65 kV. Using LDPC reconstruction the voxel noise is reduced from 170 HU to 30 HU, on average, and artifacts are almost completely removed. The dose of our standard protocol is about 500 mGy. Reducing the number of rotations available for image reconstruction shows that we can get comparable image quality with only 125 mGy. Compared to other publications, that apply between 1840 to 2400 mGy dose and use PC reconstruction (similar spatial resolution and image noise) [4], our LDPC approach therefore achieves a more than ten-fold dose usage improvement. It should be noted that image noise was measured in a homogeneous volume of interest (VOI) in the liver region and it is not necessarily intersecting those slices shown in the figures.

Conclusion:

LDPC boosts image quality compared to PC and enables high fidelity low-dose double-gated imaging of free breathing rodents without compromise in image quality. Compared to the PC reconstruction image noise is significantly decreased with LDPC, and administered dose can be reduced accordingly.

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- [1] Bodea et al., *Med. Phys.* 31(12): 3324–3329, Dec. 2004.
- [2] Kachelrieß et al., *Med. Phys.* 29(7): 1489–1503, Jul. 2002.
- [3] McKinnon et al., *IEEE TBME*, 28(2): 123–127, Feb. 1981.
- [4] Drangova et al., *Investigative Radiology*, 42(2): 85–94, Feb. 2007.



Send correspondence requests to:

Prof. Dr. Marc Kachelrieß
Institute of Medical Physics (IMP), University of Erlangen-Nürnberg
Henkestr. 91, 91052 Erlangen, Germany
marc.kachelrieß@imp.uni-erlangen.de