Title: Breathing motion compensated reconstruction for C-arm cone beam CT imaging: initial experience based on animal data.

D. Schäfer[1], M. Lin[2], P.P. Rao[3], R. Loffroy[3], E. Liapi[3], N. Noordhoek[4], P. Eshuis[4], A. Radaelli[4], M. Grass[1], J.-F.H. Geschwind[3]

[1]Philips Research Europe, Hamburg, Germany; [2]Philips Research North America, Briarcliff, NY, USA; [3]The Johns Hopkins University School of Medicine, Vascular and Interventional Radiology, Baltimore, MD, USA; [4]Philips Healthcare, Interventional X-ray, Best, The Netherlands

Abstract: C-arm based tomographic 3D imaging is applied in an increasing number of minimal invasive procedures. Due to the limited acquisition speed for a complete projection data set required for tomographic reconstruction, breathing motion is a potential source of artifacts. This is the case for patients who cannot comply breathing commands (e.g. due to anesthesia). Intra-scan motion estimation and compensation is required. Here, a scheme for projection based local breathing motion estimation is combined with an anatomy adapted interpolation strategy and subsequent motion compensated filtered back projection. The breathing motion vector is measured as a displacement vector on the projections of a tomographic short scan acquisition using the diaphragm as a landmark. Scaling of the displacement to the acquisition iso-center and anatomy adapted volumetric motion vector field interpolation delivers a 3D motion vector field per voxel. Motion compensated filtered back projection incorporates this motion vector field in the image reconstruction process. This approach is applied in animal experiments on a flat panel C-arm system delivering improved image quality (lower artifact levels, improved tumor delineation) in 3D liver tumor imaging.

Purpose: C-arm based tomographic 3D imaging is applied in an increasing number of minimal invasive procedures [1]. Next to 3D rotational angiographic imaging, new acquisition, detection and reconstruction strategies enable CT like low contrast 3D imaging at high spatial resolution in interventional radiology [2]. Due to the limited acquisition speed of a projection data set sufficient for tomographic reconstruction, breathing motion is a potential source of artifacts in interventional applications. Typical rotational acquisition protocols have durations of 5-20 sec. This results in excellent image quality for patients with breath hold. In case of less healthy patients which can not comply or patients under anesthesia motion artifacts can occur. Intra-scan motion estimation and compensation is required. In the following, a scheme for projection based local breathing motion estimation is combined with an anatomy adapted interpolation strategy and subsequent motion compensated filtered back projection. This approach is applied in animal experiments on a flat panel based C-arm system to improve the image quality in 3D liver tumor imaging. Here, rabbits with an implanted VX-2 liver tumor model are imaged for translational liver cancer research utilizing an imaging system also used in human interventional oncology applications.

Methods: Since short scan rotational X-ray acquisitions do not contain redundant cone-beam data, projection based motion estimation must be used to determine the breathing motion pattern. As an indicator for the breathing motion the diaphragm region is selected. When using a circular short scan for the projection acquisition, the location of this region of interest (ROI) remains in a relatively fixed area on the projection during the rotational run. This ROI is selected, gradient filtered (see Fig. 1), and integrated along the projection of the tangential of the source trajectory on the detector plane (see Fig. 2).

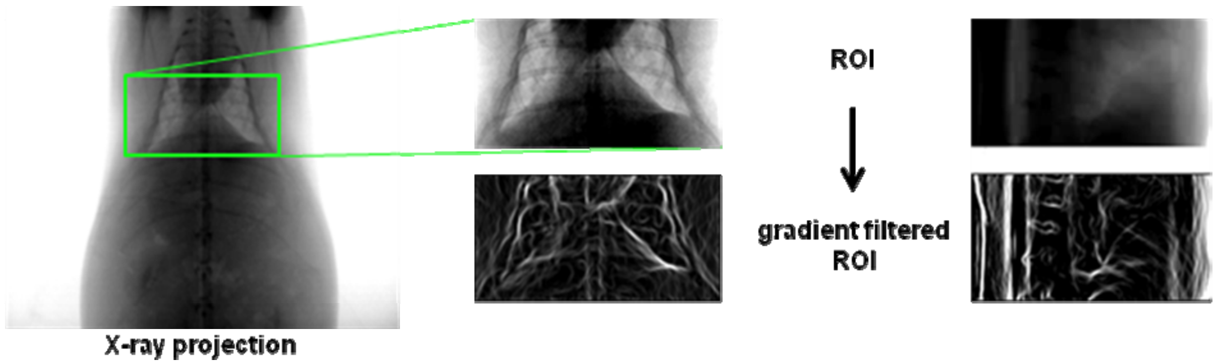

Fig. 1: Original projection of the rabbit model (left image) and two selected region of interest projections (middle and right column) before and after gradient filtering (upper and lower image).

The diaphragm motion is estimated by cross-correlation analysis of the filtered and integrated ROIs and a caudo-cranial shift vector is derived [3]. Subsequently, the ribcage and diaphragm are semi-automatically segmented from a standard 3D filtered back projection cone-beam reconstruction [4] using Sobel filtered volume data and a manual seed point segmentation. A 3D motion vector field (MVF) is interpolated for every voxel by keeping the ribcage static and applying the detected motion to the diaphragm using distance weighted scattered data interpolation from three nearest neighbour points of the MVF [5]. The motion-compensated cone beam filtered back projection reconstruction is obtained by applying the motion vector during back-projection [6].

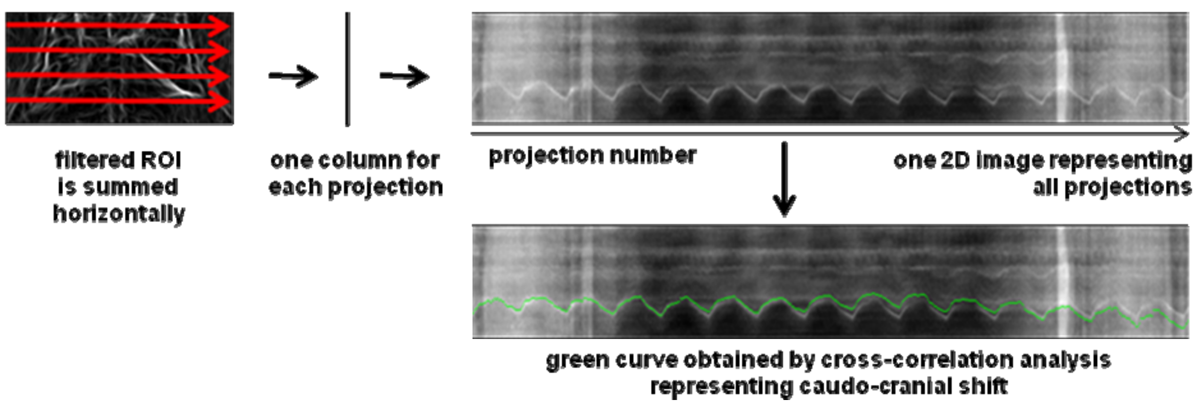

Fig. 2: Filtered ROI projection with the integration direction indicated by red arrows (left image). 2D images with each column representing the filtered and integrate ROI of one projection without (upper right image) and with (lower right image) a line indicating the diaphragm motion.

Results: Projection data have been acquired at John's Hopkins University, Baltimore, USA using a commercial C-arm system (Allura XperFD20, Philips Healthcare, Best, The Netherlands) with a low contrast XperCT protocol for translational interventional research with the VX2 rabbit liver tumor model. Small physical size and rapid cardio-ventilatory motion in the rabbit poses a challenge in producing adequate imaging. Three different acquisition protocols have been used to acquire the data: A – 20 sec scan time, 30 fps acquisition speed, 5 msec pulse length; B – 10 sec, 30 fps, 5 msec;

C – 5 sec, 60 fps, 5 msec. Images have been reconstructed using cone beam filtered back projection with and without motion compensation. The image quality was assessed based on image contrast, artifacts, and tumor delineation.

For the standard reconstruction the image quality improved with decreasing scan time. For all protocols the motion compensation improved the image quality with respect to image contrast, artifact level and tumor delineation (one example given in Fig. 3).

Conclusions: Motion compensation of the rabbit ventilation resulted in improved IQ and can enable use of clinical C-arm systems for pre-clinical imaging to facilitate translational imaging research. Potential transfer of this technique to human applications requires further evaluation.

New or breakthrough work presented: Sharp tumor delineation is possible with intra-scan breathing motion compensation.

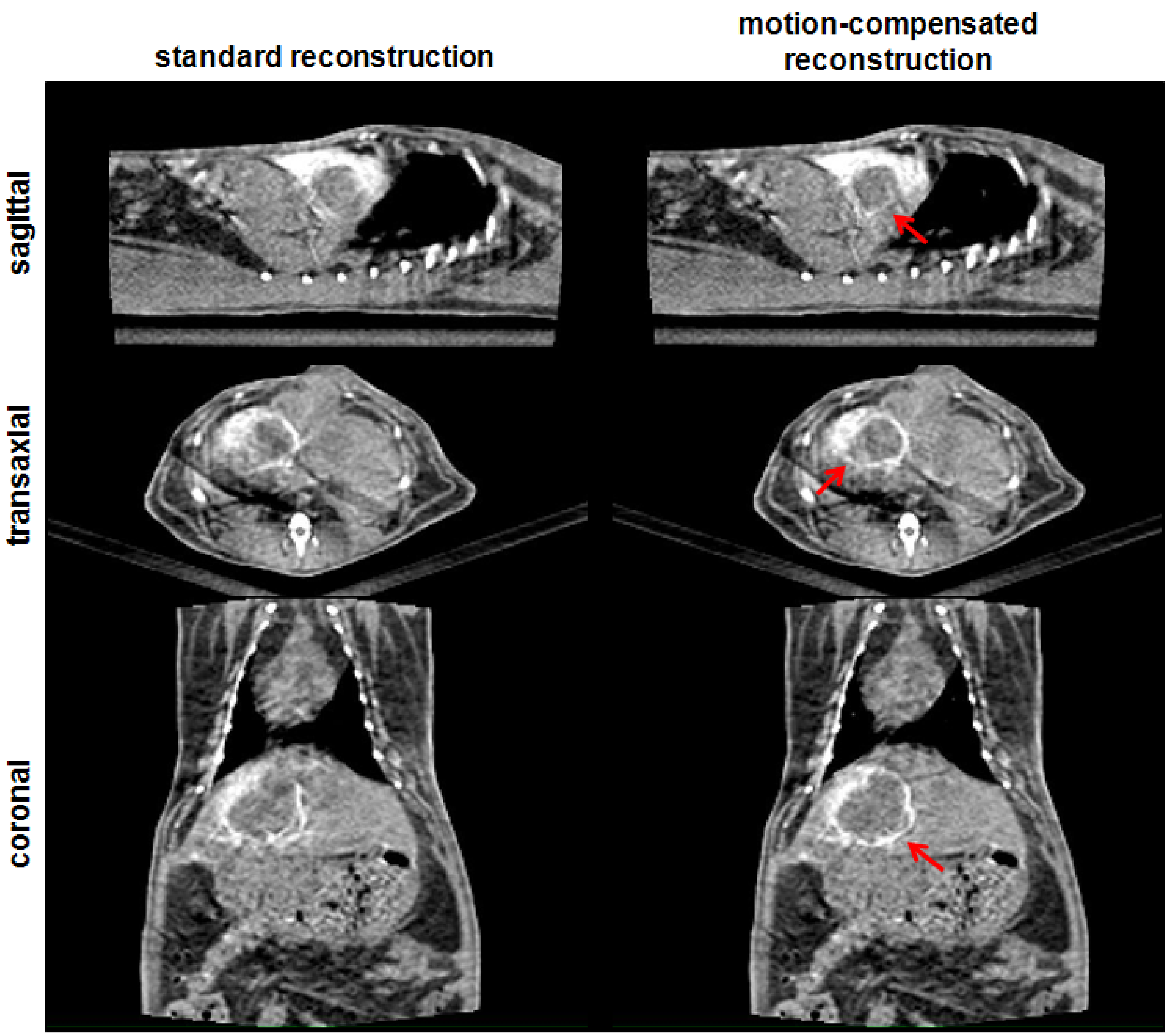

Fig. 3: Comparison of the image quality for an animal scan with a standard reconstruction (left column) and a motion compensated reconstruction (right column). Reconstruction has been performed with 1mm voxel size from 308 projections acquired in 5 sec (L: 150 / W: 500 HU).

References:

[1] Wallace, M., Kuo, M., Glaiberman, C., Binkert, C., Orth, R., Soulez, G., “Three-dimensional C-arm cone beam CT: Applications in the intervention suite”, J. Vasc. Interv. Radiol. 19, pp. 799-813 (2008).

[2] Grass, M., Guillemaud, R., and Rasche, V., “Interventional X-ray volume tomography”, Chapter 11 in: “Tomography”, Editor: P. Grangeat, Wiley, NJ, USA (2009).

[3] Jandt, U., Schäfer, D., Grass, M., and Rasche, V., “Automatic cardiac phase point selection for 3D rotational coronary angiography”, Int. J. Computer Assisted Radiology and Surgery CARS 2 (1), pp. S77–79 (2007).

[4] Feldkamp, L.A., Davis, L.C., and Kress, J.W., “Practical cone beam algorithms”, J. Opt. Soc. Am. A6, pp. 612-619 (1984).

[5] Forthmann, P., van Stevendaal, U., Grass, M., and Köhler, T., “Vector field interpolation for cardiac motion compensated reconstruction”, IEEE NSS-MIC Conf. Rec. 2008, pp. 4157-4160 (2008).

[6] Schäfer, D., Borgert, J., Rasche, V., and Grass, M., “Motion-compensated and gated cone beam filtered back-projection for 3-D rotational X-Ray angiography”, IEEE Trans. Med. Imag. 25 (7), pp. 898-906 (2006).