5D Motion Compensation for CBCT of the Thorax Region in IGRT

S. Sauppe[1], C. M. Rank[1], A. Hahn[1], M. Brehm[2], P. Paysan[2], D. Seghers[2], and M. Kachelrieß[1]

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

[2]Varian Medical Systems Imaging Laboratory, Baden-Dättwil, Switzerland

send correspondence to: sebastian.sauppe@dkfz.de

GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

50 Years – Research for A Life Without Cancer

Introduction

Accurate information about patient motion is essential for precise radiation therapy, in particular for thoracic and abdominal cases. Motion compensation based on daily on-board CBCT images before treatment beam-on would allow us to adapt the treatment plan instantly. Especially for patients with tumors close to an organ of risk, the patient position verification has to be very precise and can be enhanced by taking motion into account based on 5D CBCT images. But retrospectively gated image reconstructions of respiratory and cardiac phase-correlated projections contain severe sparse projection artifacts. We propose an adapted method of our previously published 5D motion compensation (MoCo) algorithm [1], developed for micro-CT imaging of small animals, to improve the image quality of those CBCT scans.

Materials and Methods

Clinical patient data acquired with the TrueBeam™ 4D CBCT system (Varian Medical Systems) had been used for our study. Next to respiratory phase binning of CBCT projections, such as for 4D CBCT, cardiac phase binning is applied both based on intrinsic determined motion signals. For the intrinsic respiratory and cardiac motion signal detection, 64 overlapping region of interests are automatically evaluated in projection space. This procedure with both binning active is here denoted by double gating. We compensate respiratory and cardiac motion in a two-step procedure. First step: Respiratory motion is estimated and compensated using respiratory phase binning only. Cardiac motion is neglected there. Second Step: Cardiac motion estimation is performed using respiratory compensated images with active cardiac phase binning. The motion estimation algorithm bases on a deformable intensity-based 3D-3D image registration method.

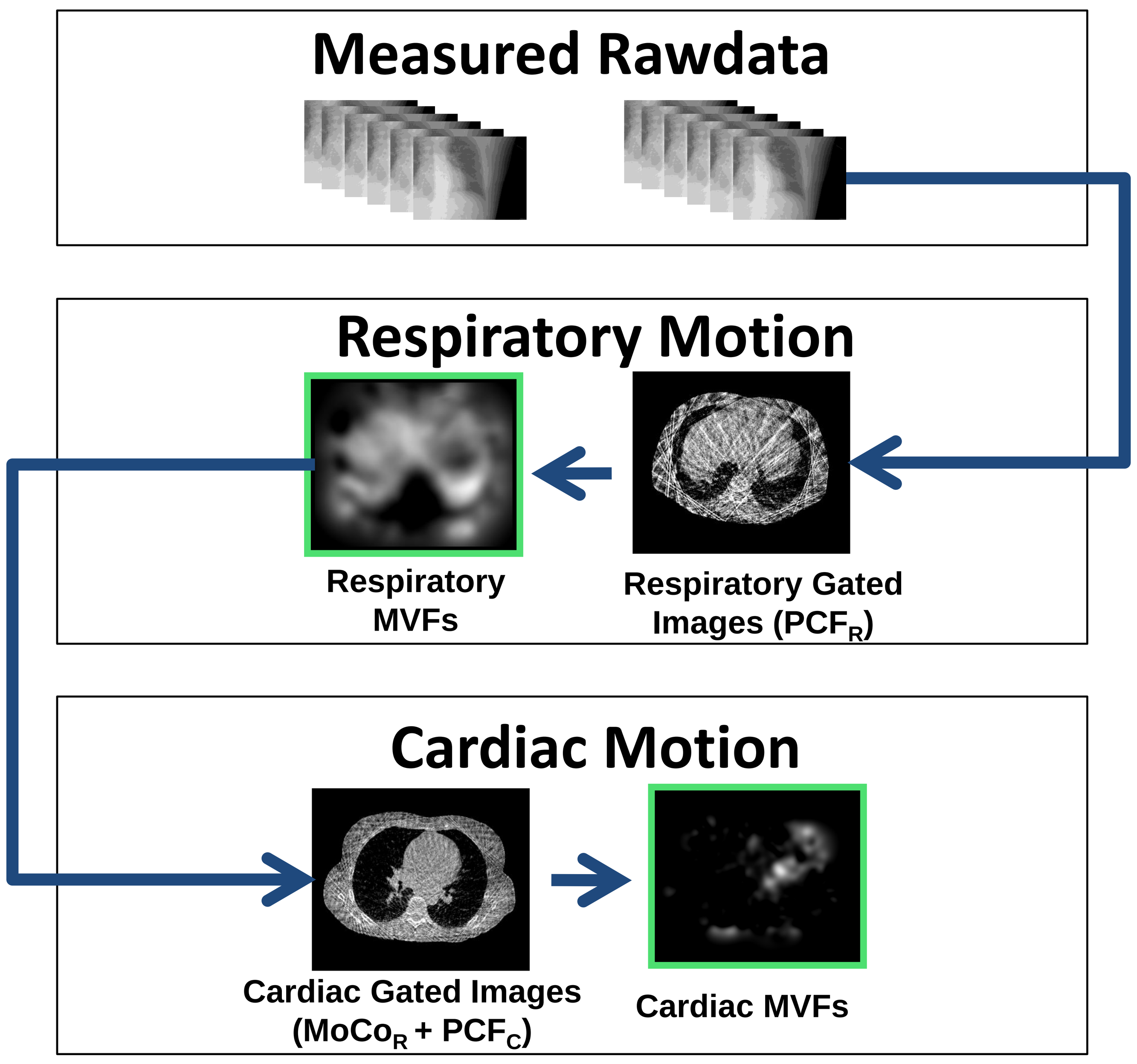

Figure 1 – Workflow for a two step cardiorespiratory (5D) motion compensation.

$$f_{\mathrm{r,c}} = \sum_{\rho,\gamma} \mathsf{D}^{r,c}_{\rho,\gamma}\, \mathsf{X}^{-1}\, \mathsf{G}_{\rho}\, \mathsf{G}_{\gamma}\, p$$

f Image

X X-ray transform (forward projection)

X^{-1} Backprojection (FDK)

p Rawdata

D^r_ρ Deformation operator

G_ρ Gating operator

Combining the obtained motion vector fields for respiratory and cardiac motion allows us to compensate motion for any arbitrary respiratory and cardiac target phases.

Results

Either 5D double gated or respiratory-compensated plus cardiac-gated images both contain strong streak artifacts and high noise levels. We could improve the spatial resolution and noise level significantly by our 5D MoCo approach while still providing a high temporal resolution for respiratory and cardiac motion. Because nearly all severe sparse projection streak artifacts are removed, small structures can be delineated even in areas where motion is high. Noise level of patient data is the same than for a standard 3D reconstruction due to making use of 100 % of the projection data for each reconstructed frame. Figure 2 gives an overview of different CBCT image reconstruction algorithms**.** From left to right: standard 3D Feldkamp reconstruction, 4D MoCo, respiratory and cardiac gated images, 4D MoCo and subsequently cardiac gating, 5D MoCo.

Acknowledgements

This study was supported by Varian Medical Systems.

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

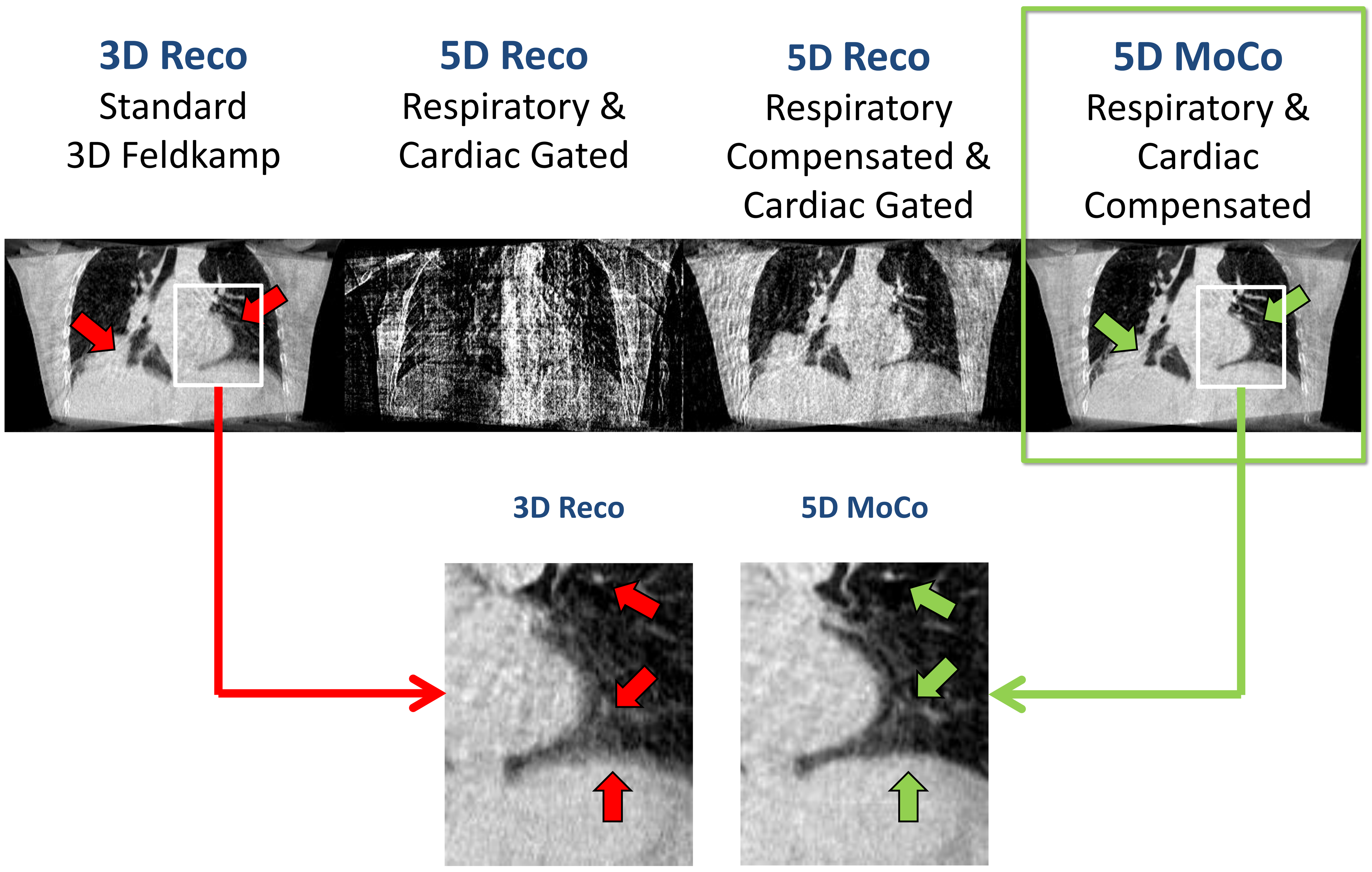

Figure 2 – Comparison of different CBCT image reconstructions.

For all images a window level of -250 HU and a window width of 1400 HU was applied.

[1] Brehm, M., Sawall, S., Maier, J., Sauppe, S., and Kachelrieß, M., “Cardiorespiratory motion–compensated micro–CT image reconstruction using an artifact model–based motion estimation,” Med. Phys. 42, 1948 – 1958 (Apr. 2015).