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# 4D cone-beam computed tomography using motion-aware regularization

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**Abstract -** *In Image-Guided RadioTherapy (IGRT) of lung tumors, patients undergo a 4D CT, on the basis of which their treatment is planned. It is implicitly assumed that their breathing motion will not change much throughout the treatment. At the beginning of a treatment fraction, a Cone Beam CT (CBCT) acquisition is performed, and used to re-position the patient. Obtaining a 4D reconstruction from this cone beam data would allow the therapists to check whether the breathing motion of the day still matches that of the planning CT, and if not, take appropriate corrective actions. But 4D tomography from a single cone beam CT acquisition implies a severe lack of projection data, and efficient methods have only started to appear during the last few years. Some perform regularization along time to explicitly enforce similarity between consecutive frames, which considerably improves image quality. In IGRT, breathing motion can be estimated on the 4D planning CT, and used to refine the 4D CBCT reconstruction results. We describe a 4D CBCT reconstruction method that combines regularization techniques with the use of motion information.*

**Index Terms -** *Image Processing, Radiotherapy, X-Ray imaging*

## I. INTRODUCTION

In image-guided radiotherapy (IGRT) of lung tumors, breathing motion affects the image guidance. On a treatment day, physicians currently have no reliable method to make sure that the patient's breathing motion is the same as in the planning CT. This task requires a 4D reconstruction of the cone beam CT data, but most reconstruction methods currently available suffer major drawbacks: static reconstruction techniques, like FDK [1] or SART [2], generate images almost free of streaks, but in 3D, not 4D, and in which the moving structures are strongly blurred. Their respiration-correlated counterparts generate severely degraded 4D images with strong streak artifacts, unless the acquisition time is substantially increased [3]. Advanced methods have been developed to achieve streak-free and blur-free 4D reconstructions. Mostly, they are based either on motion compensation [4, 5] or on regularization using some a priori information [6, 7]. Recently, mixed methods have been proposed, which combine both approaches [8].

We describe a new mixed 4D reconstruction method that combines regularization techniques with the use of motion information, and show its results on real patient data.

## II. MATERIALS AND METHODS

Our method, coined Motion-Compensated RecOnstruction using Spatial and TEmporal Regularization (MC-ROOSTER), assumes that a rough segmentation of the patient is available. Movement is expected to occur only inside the segmented region. It also requires a 4D Deformation Vector Field (DVF) describing the patient's breathing motion. The algorithm consists in iteratively enforcing five different constraints in an alternating manner:

- Minimize a quadratic data-attachment term  $\sum_{\alpha} \|R_{\alpha} S_{\alpha} f - p_{\alpha}\|_2^2$ , with  $\alpha$  the projection's index,  $f$  a 4D sequence of volumes,  $R_{\alpha}$  the forward projection operator for the projection with index  $\alpha$ ,  $S_{\alpha}$  a linear interpolator which, from the 4D sequence  $f$ , estimates the 3D volume through which projection  $\alpha$  has been acquired, and  $p_{\alpha}$  the measured projection with index  $\alpha$ . Minimization is performed by conjugate gradient
- Enforce positivity
- Average along time outside the segmentation, removing motion everywhere but in the segmented region, yielding  $f_{Averaged}$
- Perform spatial Total Variation (TV) denoising on each 3D volume of  $f$  independently, i.e. solve  $f_{Space} = \arg \min_f \|f - f_{Averaged}\|_2^2 + \gamma_{Space} TV_{Space}(f)$
- Perform temporal TV denoising along curved trajectories determined by the 4D DVF, i.e. compute  $f_{Denoised} = W^{-1} D_{time}(W f_{Space})$ , with  $D_{time}$  the total variation denoising along time operator (similar to spatial TV denoising),  $W$  the trilinear interpolation warping operator applying the DVF's motion, and  $W^{-1}$  its inverse

This constitutes one iteration of the main loop, the output of which is fed back to the conjugate gradient minimizer for the next iteration.

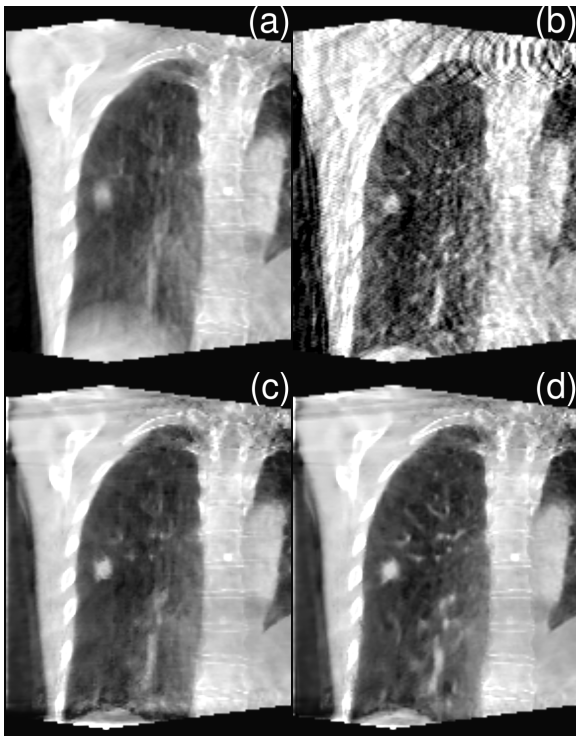


Figure 1: Coronal slice of patient with lung tumor, in end-inhale position (a) Static FDK (b) Respiration-correlated FDK (c) MC-ROOSTER with null DVF (d) MC-ROOSTER with DVF estimated on the planning CT

### III. RESULTS

A CBCT acquisition performed on a patient was reconstructed with static 3D FDK, respiration-correlated FDK, and MC-ROOSTER with either a null DVF or the one estimated on the 4D planning CT. Estimation was performed using a method that allows sliding motion at the border between the lungs and the chest wall [9]. The size of the reconstructed sequence of volumes was set to  $145 \times 185 \times 245$  voxels, with isotropic voxels of size 1.5 mm in each dimension. The results are displayed in Figure 1. The static FDK reconstruction is very blurry, and the respiration-correlated one is degraded by strong streak artifacts (although they do not appear as streaks with this cut plane). Without motion information (sub-figure (c)), MC-ROOSTER already provides a usable 4D reconstruction: the small structures are partially blurred out, but the tumor is correctly reconstructed. Making use of relevant motion information (sub-figure (d)) dramatically increases the preservation of small structures.

### IV. DISCUSSION-CONCLUSION

This paper shows that MC-ROOSTER can be employed for 4D CBCT of the lungs. Motion information can be used to

improve the reconstruction result, but it also works without any a priori information on motion.

We have shown that high-quality 4D CBCT of the lungs from a single rotation is possible, and that a method based on regularization can be considerably improved by making the regularization along time “motion-aware”.

### REFERENCES

- [1] L. A. Feldkamp, L. C. Davis, and J. W. Kress, “Practical cone-beam algorithm,” *Journal of the Optical Society of America A*, vol. 1, no. 6, pp. 612–619, Jun. 1984.
- [2] A. H. Andersen and A. C. Kak, “Simultaneous algebraic reconstruction technique (SART): a superior implementation of the art algorithm,” *Ultrasonic Imaging*, vol. 6, no. 1, pp. 81–94, Jan. 1984.
- [3] J.-J. Sonke, L. Zijp, P. Remeijer, and M. van Herk, “Respiratory correlated cone beam CT,” *Medical Physics*, vol. 32, no. 4, p. 1176, 2005.
- [4] S. Rit, J. W. H. Wolthaus, M. van Herk, and J.-J. Sonke, “On-the-fly motion-compensated cone-beam CT using an a priori model of the respiratory motion,” *Medical physics*, vol. 36, no. 6, pp. 2283–2296, Jun. 2009.
- [5] J. Wang and X. Gu, “High-quality four-dimensional cone-beam CT by deforming prior images,” *Physics in Medicine and Biology*, vol. 58, no. 2, p. 231, Jan. 2013.
- [6] F. Bergner, T. Berkus, M. Oelhafen, P. Kunz, T. Pan, R. Grimmer, L. Ritschl, and M. Kachelrie, “An investigation of 4d cone-beam CT algorithms for slowly rotating scanners,” *Medical Physics*, vol. 37, no. 9, p. 5044, 2010.
- [7] C. Mory, V. Auvray, B. Zhang, M. Grass, D. Schfer, S. J. Chen, J. D. Carroll, S. Rit, F. Peyrin, P. Douek, and L. Boussel, “Cardiac c-arm computed tomography using a 3d + time ROI reconstruction method with spatial and temporal regularization,” *Medical physics*, vol. 41, no. 2, p. 021903, Feb. 2014.
- [8] J. Wang and X. Gu, “Simultaneous motion estimation and image reconstruction (SMEIR) for 4d cone-beam CT,” *Medical Physics*, vol. 40, no. 10, p. 101912, Oct. 2013.
- [9] V. Delmon, S. Rit, R. Pinho, and D. Sarrut, “Registration of sliding objects using direction dependent b-splines decomposition,” *Physics in Medicine and Biology*, vol. 58, no. 5, p. 1303, Mar. 2013.