Respiration Motion Assessment of Liver Tumor Using 4D Cone-beam Computer Tomography Technique

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Motivation

Ren *et. al.* have proposed a novel CBCT estimation method by deforming planning CT images imag [1].

It has been showed that the method has better performance than standard FDK method in terms of detecting inter-fraction organ motion and volume changes, when the scan angle is limited and the number of X-ray projections is low[2].

In this study, we extend Ren's method to 4D free-breathing CBCT scans and use it to detect three-dimensional tumor motion.

Method

- In this study, breath-hold(BH) CBCT scan and free-breath (FB)-CBCT scan were acquired in the same position.
- Prior information: BH-CBCT image set $I^{BH}(x,y,z)$ reconstructed using FDK algorithm.
- Deformation to be solved: BH-CBCT ⇨ FB-CBCT
- Use deformation map $V^t(x,y,z)$ to represent organ and tumor motion at frame t during free-breath(FB) CBCT scan.
- FB-CBCT image at frame t was estimated by the deformed BH-CBCT images $I^{BH}(x+V^t_x, y+ V^t_y, z+V^t_z)$

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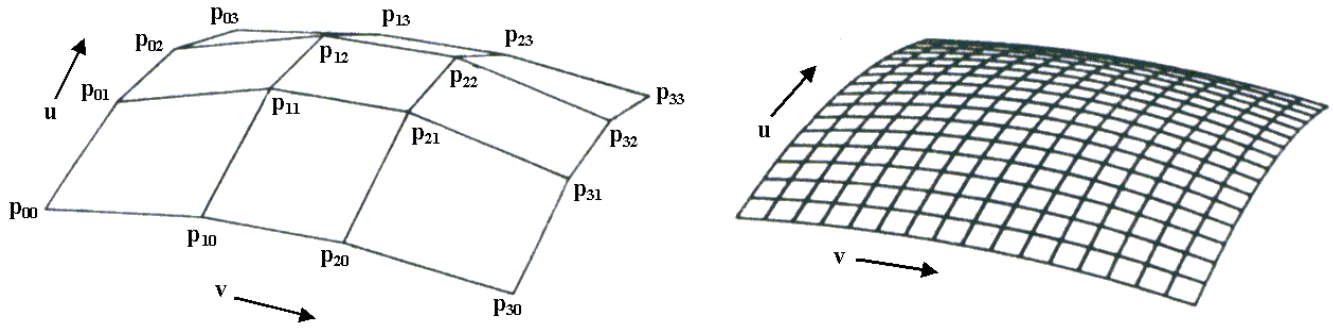
B-spline based deformation

- To ensure smooth deformation, the deformation map $V^t(x,y,z)$ was characterized by a set of deformation vectors $U^t(u,v,w)$ at equally-spaced grid points.



- The deformation map off the grid points was calculated based on cubic B-spline interpolation.

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- We chose B-spline interpolations instead of adding extra constraints such as bending energy as in [1][2],

$$E(V) = \iiint \left(\left(\frac{\partial^2 V}{\partial x^2} \right)^2 + \left(\frac{\partial^2 V}{\partial y^2} \right)^2 + \left(\frac{\partial^2 V}{\partial z^2} \right)^2 + 2\left(\frac{\partial^2 V}{\partial x \partial y} \right)^2 + 2\left(\frac{\partial^2 V}{\partial y \partial z} \right)^2 + 2\left(\frac{\partial^2 V}{\partial x \partial z} \right)^2 \right) dx dy dz$$

- The strength of extra constraints depends on image quality and need to be optimized through simulations.
- By using B-spline method, we can intuitively choose grid size based on anatomy and the setting is independent of imaging quality.

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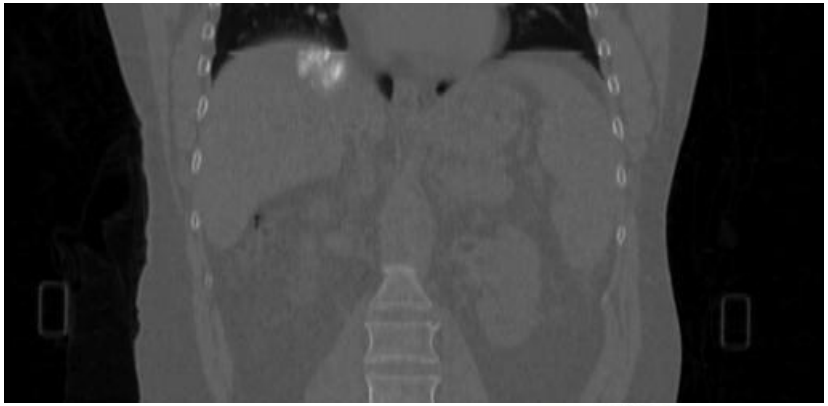
Currently, 4D imaging is available for simulation & planning, but not for patient setup & treatment



CT Scan for simulation

Cone beam (CB) CT Scan for setup

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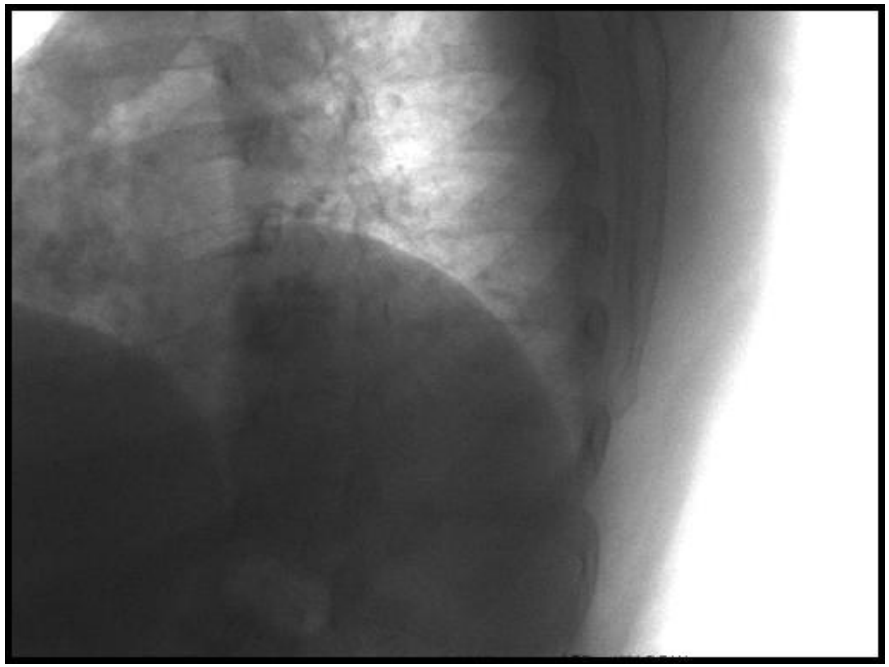
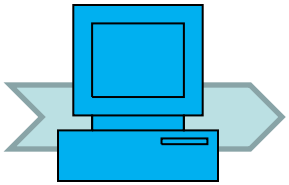
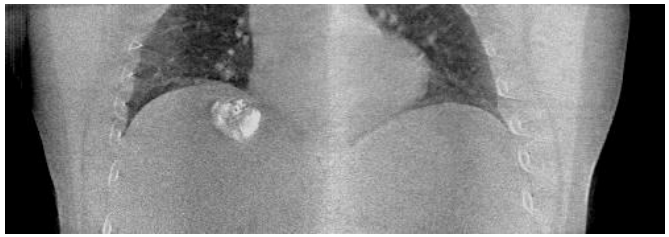
Breath-hold during CBCT acquisition

No respiration movement







3D anatomy can be reconstructed based on the projection sequence (>300 projections).
Not all patients can hold his/her breath. Even for those who can, the 60 second CBCT scan need to be split in 2-3 sessions.

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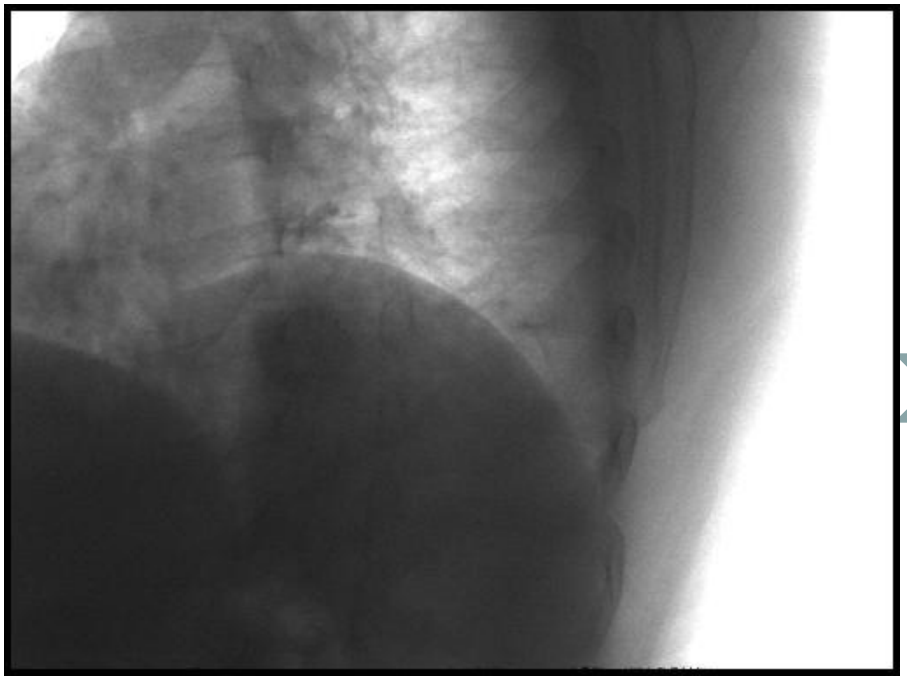
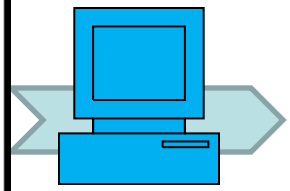
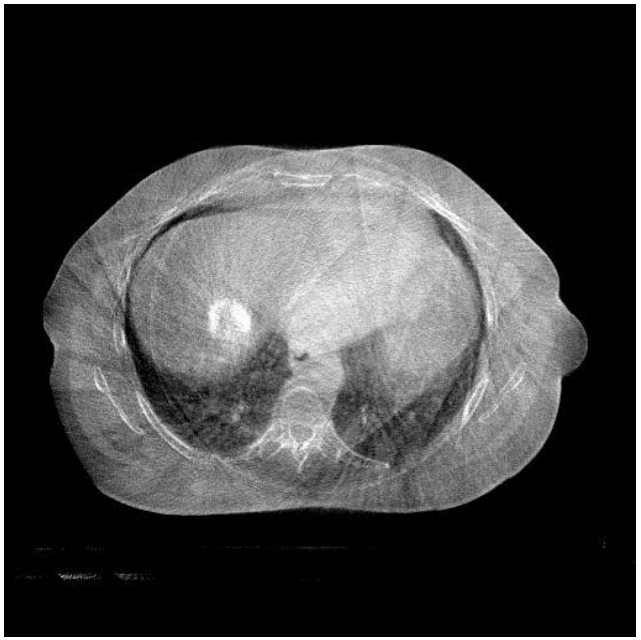
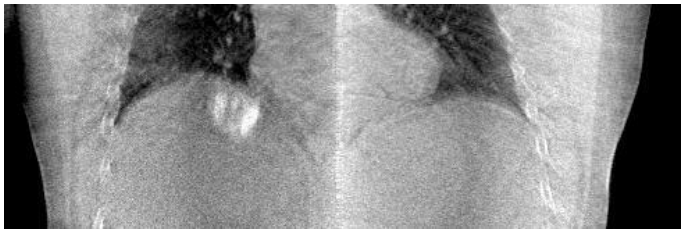
Free-breathing during CBCT acquisition

1-2 cm superior-inferior movement









Free-breathing CBCT is applicable to all patients. However, standard 3D CT reconstruction algorithm can not resolve the motion. New 4D reconstruction method is needed.

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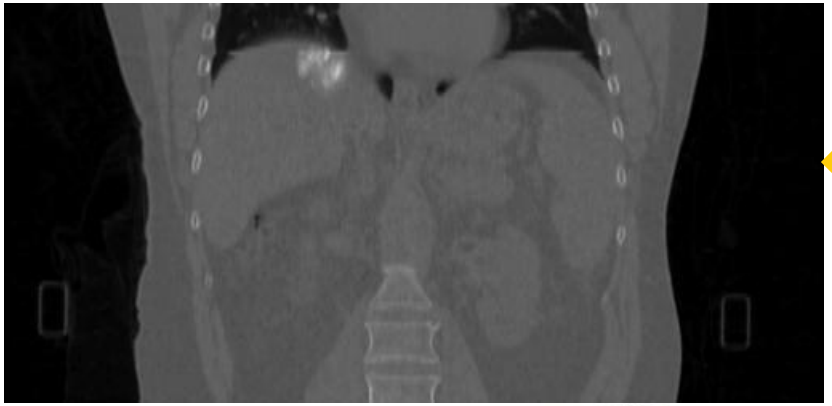

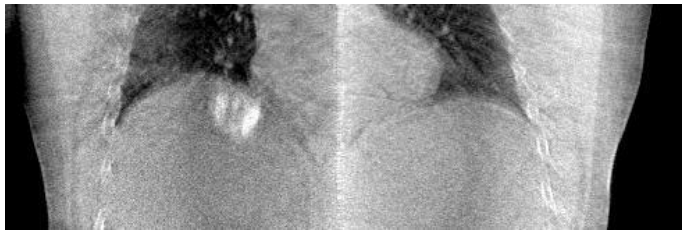

CT Scan for simulation

Cone beam (CB) CT Scan for setup

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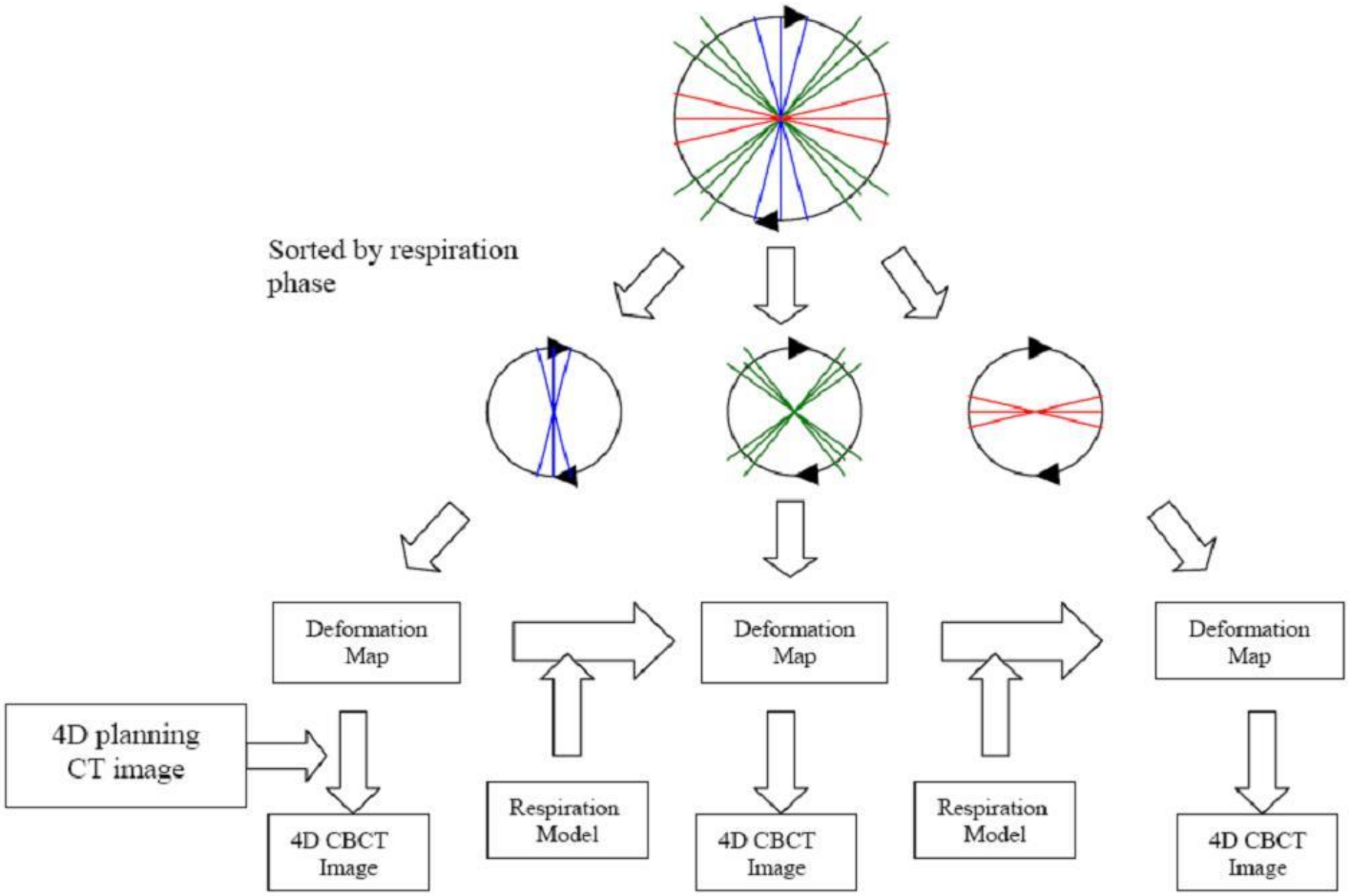
Reconstruction Scheme



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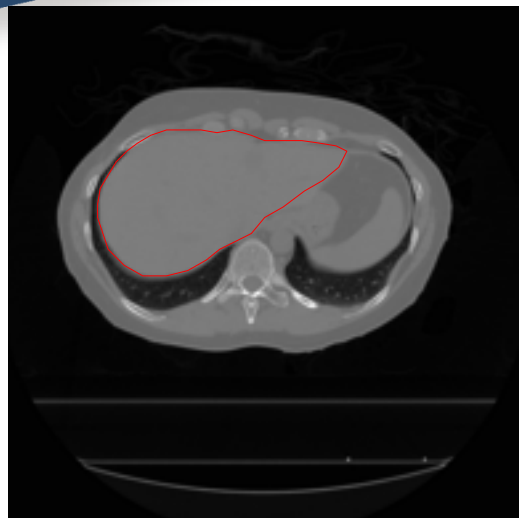
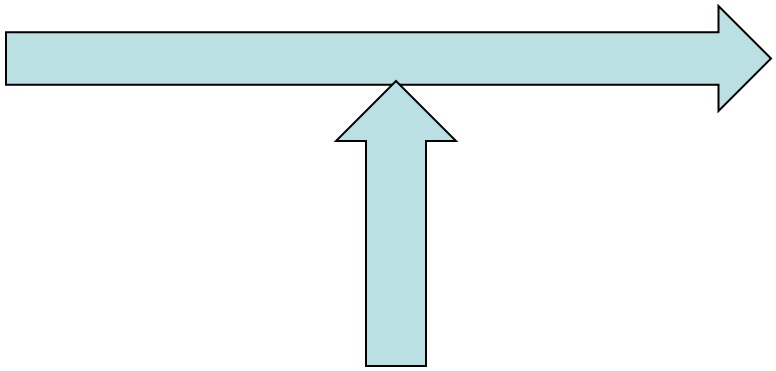
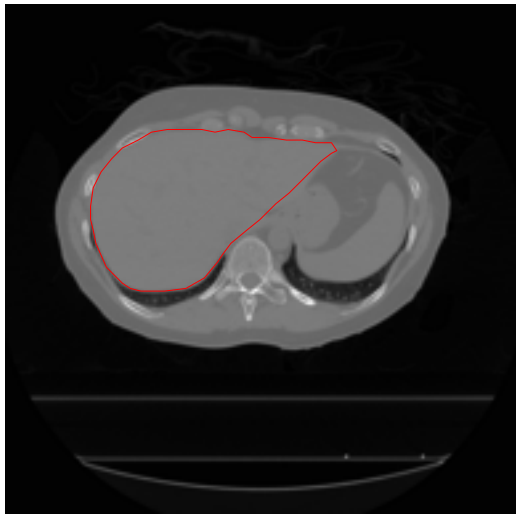
New strategy: Reconstruct CBCT using deformation field

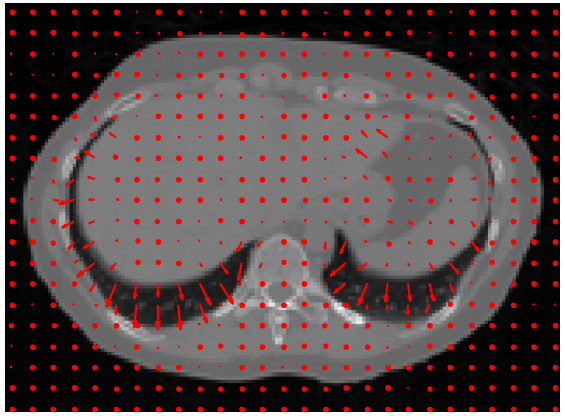






CBCT

Prior image:
e.g. Planning CT



Solved deformation field

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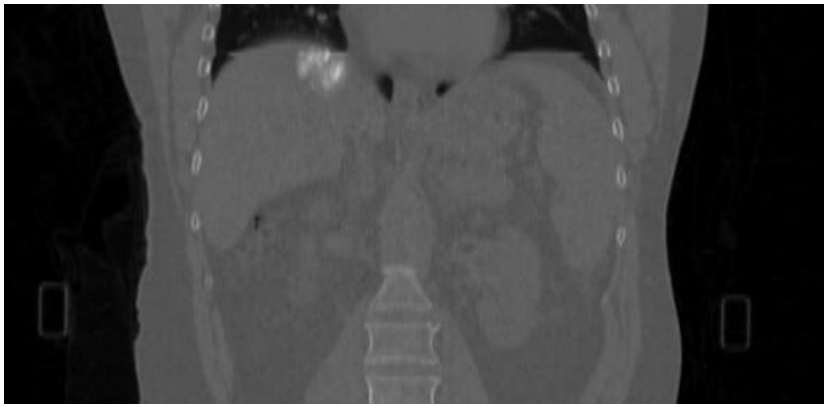
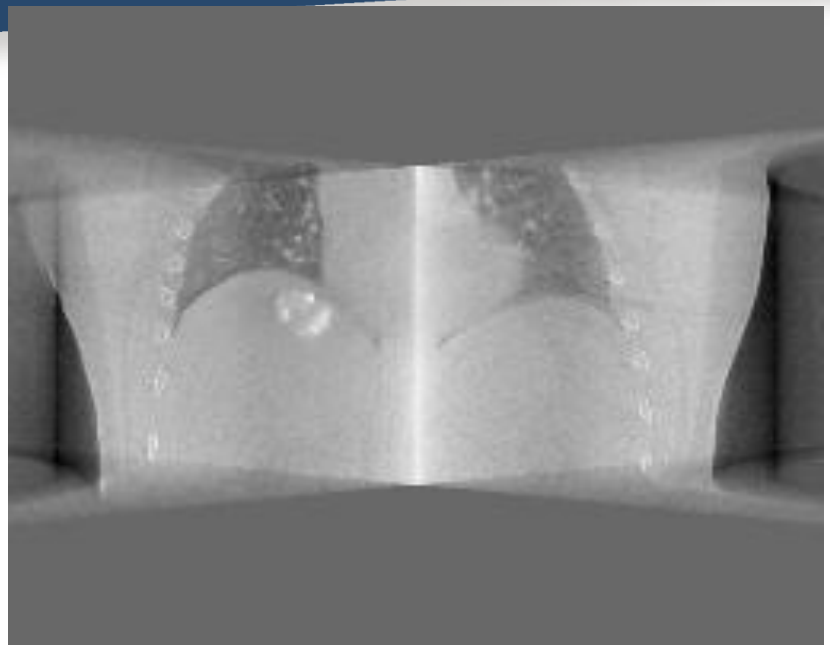
Result



4D CT acquired in simulation



4D CBCT reconstructed from projections

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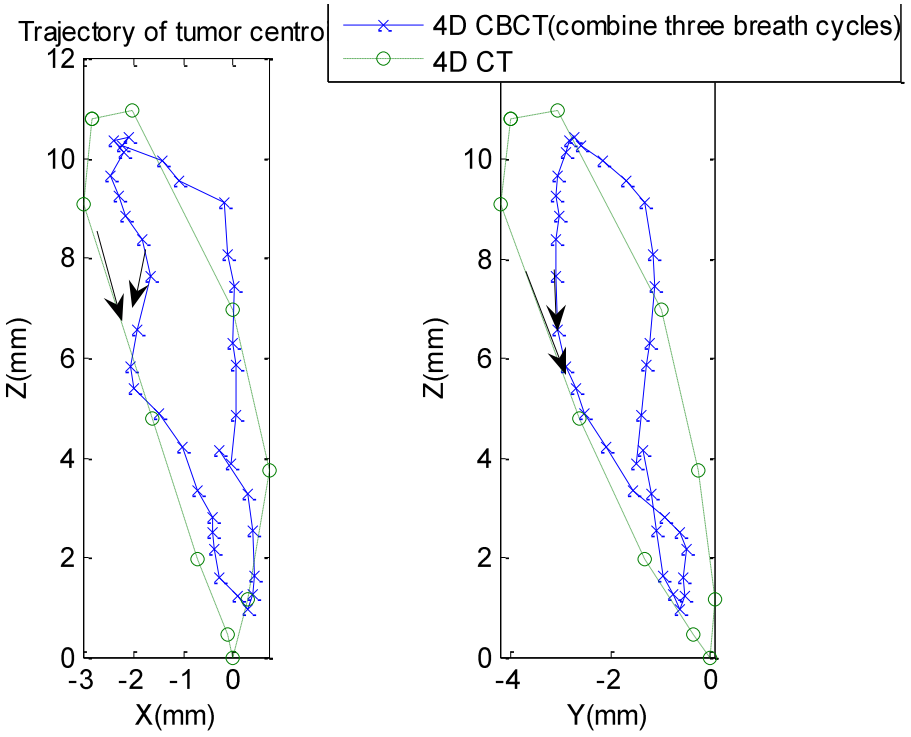
Compare tumor trajectory in 4D CT and 4D CBCT

- Using 4D CBCT, the tumor was detected to have 9.5 mm movement along the sup/inf direction. Compared with the 4D CT value 11.0mm, the error was 1.5 mm or 14%.
- ***Conclusion:*** The pivot study showed that the proposed method can detect the movement of live tumor.



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Reference

- [1] L. Ren, J. Zhang, D. Thongphiew, D. J. Godfrey, Q. J. Wu, S. Zhou, and F. Yin, “A novel digital tomosynthesis (DTS) reconstruction method using a deformation field map”, *Medical Physics*, Vol 35, Issue 7, July 2008, pp. 3110-3115.
- [2] Lei Ren., Indrin J. Chetty, Junan Zhang, Jian-Yue Jin, Q. Jackie Wu, Hui Yan, David M. Brizel, W. Robert Lee, Christopher G. Willett, Benjamin Movsas, Fang-Fang Yin, Ph.D. “Optimization and Clinical Evaluation of a 3D Cone-Beam CT (CBCT) Estimation Method Using a Deformation Field Map”, *Int J Radiat Oncol Biol Phys.* 2010,

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