Tetrahedron Beam Computed Tomography Based On Multi-Pixel X-Ray Source and Its Application in Image Guided Radiotherapy

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Financial disclosure

- Patent royalty from AccuRay
- Research grants from NIH and DOD

Onboard imaging modality for IGRT







Convenient to use Poor image quality Stereoscopic realtime imaging No 3D imaging

g Soft tissue contrast and accurate HU Inconvenient and no 2D realtime imaging

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Limitations of CBCT in IGRT





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Lack of soft tissue contrast and strong image artifact do not support deformable image registration and auto-segmentation, which are mandatory in online and offline adaptive radiotherapy.

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Limitations of CBCT in image guided proton therapy (IGPT)



Drawback of CBCT in real-time imaging



Tetrahedron Beam Computed Tomography (TBCT)



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Principle of volumetric imaging by TBCT



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Advantages of TBCT

- 1. Scatter rejection
- 2. Compact geometry
- 3. Comparable to high quality discrete CT detectors and photon counting detectors
- 4. Lower x-ray exposure



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Existing problem #1: Approximate cone reconstruction artifact.



Images show 24 $^\circ$ cone angle. XVI's maximum cone angle = 11.4 degree.

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Existing problem #2: motion artifact

- TBCT is limited by gantry rotation speed
- · Reconstructed images show blurring due
- to inconsistent projection data
- Respiration-correlated FDK (rc-FDK) contains streak artifacts due to few projection angles.

Solution: 4D iterative reconstruction





rc-FDK

4D iterative image reconstruction



Other references: 1. Jing Wang, et al, "Simultaneous mot 2. GH, Chen, et al, "Prior image cons sets." Med Phys, 2008, 35(2): 660-3 d image reconstruction (SMEIR) for 4D CBCT", Med Phys 40(10), 101912 ed sensing (PICCS): a method to accurately reconstruct dynamic CT images from highly undersi



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Limitation of CBCT in real-time imaging





Dual-source TBCT for IGRT



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Dual-source TBCT stereoscopic imaging





Collimator design



Image quality comparison
Philips Fan beam CT TBCT benchtop





Rooms to improve for TBCT benchtop 1. Higher tube power. 2. Small detector pixel size (current 2.54mm) 3. Small focal spot size (current 1x2 mm²) Witshington University School of Medicine in St.Louis

Thermionic cathodes



Focal spot size measurement







Focal spot size $\sim\!0.5\text{--}1\,\text{mm}$

90 kVp, ~40 mA

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TBCT tube power requirement



 $\frac{\textit{TBCT Power}}{\textit{FBCT Power}} = \frac{\textit{Scanning Time of FBCT}}{\textit{Scanning Time of TBCT}} \approx 0.2$

Assuming the same source distance detector width and source filtration as helical CT. The tube power would be <10 kW, or anode current less than 100 mA. With noise suppression algorithms, tube power may be relaxed under SkW.

Thermal management for MPTEX source



 Focal spot power density is the major power limiting factor

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Focal spot temperature for short pulses





Maximum Power vs Pulse Width



Composite x-ray target material



Summary

- Tetrahedron Beam CT is a new VCT geometry based on linear x-ray source
- arrayTBCT immune to the problems of CBCT.
- TBCT can produce diagnostic grade CT images with good soft tissue contrast for adaptive radiotherapy.
 TBCT can be used for online proton dose calculation.
- TBCT can generate fast planar images for realtime imaging.
- Multi-pixel x-ray source power is limited by the focal spot power density.
- MPTEX source is able to produce sufficient power for slow gantry TBCT, especially with noise suppression algorithms.

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