DukeMedicine

X-Ray Based Real Time Imaging Verification

Lei Ren, Ph.D.
Duke University Medical Center

2015 AAPM 57th annual meeting, Educational Course, Therapy Track

Disclosure

I have received research funding from NIH, Scandidos, and Varian Medical Systems.

Why Real-Time Imaging Verification?

- Patient intra-fraction motion
  body motion, breathing change
- Uncertainties in localizing moving targets, such as lung and liver tumor
- Critical for hypo-fractionated treatment
  - Tight PTV margin
  - Long treatment time
  - High fractional dose

Potentials for Real-Time Imaging

- Reduce treatment error and PTV margin
  - Pre-treatment imaging verification
  - During-treatment imaging verification
  - Gated treatment
  - Target tracking

X-ray based Verification Techniques

- Single source: kV, MV
- Multiple sources: dual kV, kV/MV
- Gantry mounted: Linac gantry kV, MV
- Room mounted: dual kV
- Mobile: CT on-rail, C-arm

Single Source X-ray Imaging – kV Fluoro

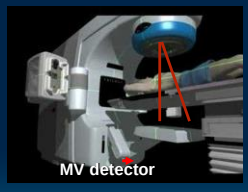
- Real-time imaging with a gantry mounted imager

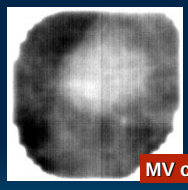
Fluoro imaging

- kV beam: 60-120 kVp, 100mA (frame rate of 15 fps)
- Imager matrix size: 1024*768 (pixel size: 0.388mm)
- Additional imaging dose to patient

Single Source X-ray Imaging – MV Cine

- Cine MV imaging with treatment beam

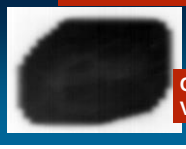




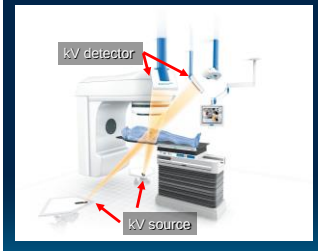
- Frame rate: ~10 fps
- Imager matrix size: 1024*768 (pixel size: 0.392mm)
- MV treatment beam, no extra imaging dose
- Reduced soft tissue contrast compared to kV fluoro

Single Source X-ray Imaging - Gating

- Gated SBRT lung treatment:



Multi-source X-ray Imaging – Dual kV



Brainlab ExacTrac

- Two oblique kV imaging beams
- Source-iso = 2.24m, source-detector=3.62m. Flat panel detector of 20cmx20cm, 0.4mm resolution
- 3D-2D rigid registration to determine the 3 rotations and 3 translations. 6D couch to correct for the misalignment
- Real time verification achieved by external marker monitoring and snap kV verification

Multi-source X-ray Imaging - Cyberknife

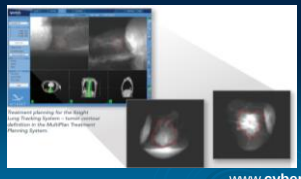
Cyberknife

- Two orthogonal kV x-ray sources and detectors
- External LED markers monitoring (25-40Hz).
- Correlation model (CM) built between external signal and internal tumor motion. Tracking based on external signal to minimize the imaging dose.
- X-ray images taken per beam basis. Model automatically updated based on new projections.

Multi-source X-ray Imaging - Cyberknife

- Markerless:
  Xsight, localization based on soft tissue or bony structure

Lung tumor >1.5cm, surrounded by air

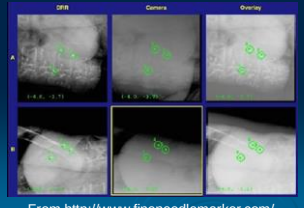


Spine

www.**cyberknife**.com

Multi-source X-ray Imaging - Cyberknife

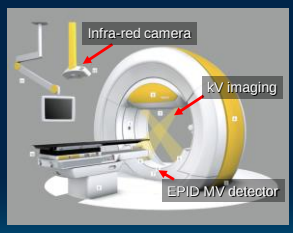
- Marker based:
  Synchrony, 3-5 fiducial markers



From http://www.fineneedlemarker.com/

Liver SBRT imaging and tracking

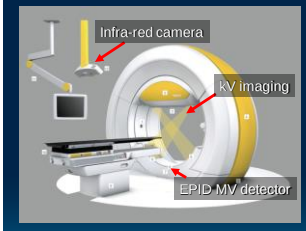
Multi-source X-ray Imaging - Vero



- Two orthogonal kV imaging systems at 45deg from MV beam axis, temporal resolution 15fps.
- EPID for MV portal imaging
- Infra-red camera for external monitoring
- Marker based tracking (marker of 0.75 mm diameter and 1-2 cm length)

Vero system by Brainlab and Mitsubishi Heavy Industry

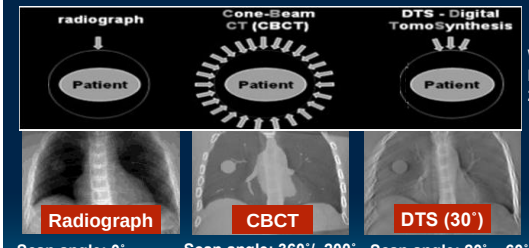
Multi-source X-ray Imaging - Vero



- Before treatment, 20-40 s repeated x-rays and IR external surrogate positions are acquired simultaneously at frame rates of 11 and 50 fps to build correlation model.
- Tracking is guided by external IR signal. Orthogonal kV imaging acquired every 1-2s to verify and rebuild the correlation model.
- MV imaging to verify beam position to determine tracking error.

Vero system by Brainlab and Mitsubishi Heavy Industry

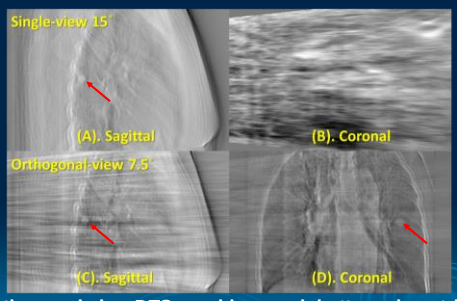
Emerging Imaging Technique - DTS



Wu et al, IJROBP, 2007

Radiograph	CBCT	DTS (30˚)
Scan angle: 0˚	Scan angle: 360˚/~200˚	Scan angle: 20˚ ~ 60˚
Scan time: <<1 s	Scan time: ~1 min	Scan time: < 10 s
Scan dose: <<1 mGy	Scan dose: ~1-8 cGy	Scan dose: < 1 cGy
Dimension: 2D	Dimension: 3D	Dimension: Quasi-3D

Emerging Imaging Technique - DTS



Orthogonal-view DTS provides much better volumetric information than single-view DTS, ~1mm accuracy

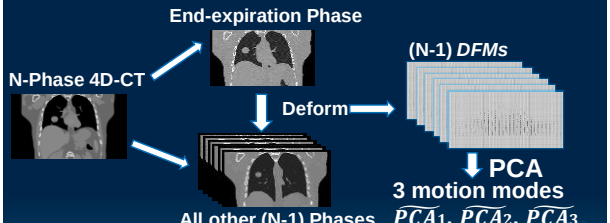
Emerging Imaging Technique - Fluoro CBCT

Principle: deform prior image to obtain on-board images

$$CBCT_{new} = Deform(D, CT_{prior})$$

Ren et al, Medical Physics, 2008

Emerging Imaging Technique - Fluoro CBCT

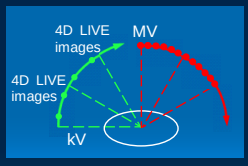


$$D = D_{0\,\mathrm{ave}} + \sum_{j=1}^{3} \widehat{w_j}\widehat{PCA_j}$$

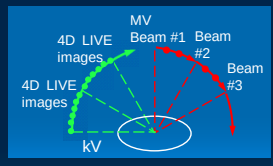
Fluoro CBCT based on a single projection.

Li et al, Medical Physics, 2010

Emerging Imaging Technique – Limited Angle Intrafraction Verification (LIVE) system



Dynamic Conformal Arc or VMAT Treatment



3D/IMRT Treatment

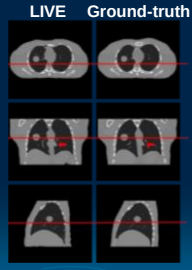
Limited angle kV/MV scan, prior image, PCA+free form deformation model

Ren et al, Medical Physics, 2014

Emerging Imaging Technique – LIVE

Concurrent kV-MV imaging during arc treatment using Truebeam Research Mode.

Emerging Imaging Technique – LIVE



15deg scan angle, ~2.5s scan time

Summary

- Real time imaging provides inter- and intra-fraction verification, which reduces the treatment error and provides basis for target tracking.
- Fast robust image analysis technique is critical for target localization in real time imaging.
- External surrogate monitoring is combined with x-ray imaging to minimize the imaging dose during real time verification. Patient breathing irregularities affect the correlation model.
- Emerging technologies, such as DTS, fluoro CBCT and LIVE, can potentially provide fast volumetric images for 4D target verification.

Acknowledgements

- Duke Radiation Oncology:
  Fang-Fang Yin, PhD
  Jing Cai, PhD
- Duke Computer Science:
  Xiaobai Sun, PhD
  Nikos Pitsianis, PhD
- Duke Medical Physics Program:
  Paul Segars, PhD
  You Zhang, PhD
  Wendy Harris

Evaluation: CIRS phantom study

Concurrent kV-MV Imaging Scheme During Treatment

DukeMedicine