Real Time Tumor Motion Tracking with CyberKnife

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Learning objectives

- Review the principles of real-time tumor motion tracking with Synchrony
- Discuss clinical applications
- Discuss tracking accuracy
- Compare it to other implementation

Disclosure

- Research support and Pilot program evaluation agreement, Accuray Inc Sunnyvale, CA
The CyberKnife system

Camera A
Camera B
Detector A
Detector B
IR Camera
Linac
Robot
Imaging and tracking system

Internal target position is calculated by comparing x-ray images with DRR.

Position of external markers (LED) is detected by optical camera – breathing cycle.

IR system
Synchronize
Correlate

Imaging System

Internal target position is calculated by comparing x-ray images with DRR.
Synchrony Motion Tracking
Automatic model

1) Peak & Valley
2) Dataset Acquisition

Synchrony Model (mm):

| 0.5 | 6.4 | 0.7 | 1.6 |
| 0.7 | 5.9 | 0.4 | 1.3 |
| 0.0 | 3.9 | 0.2 | 1.1 |
| 2.1 | 5.8 | 0.7 | 1.6 |
| 3.5 | -0.1 | -0.9 | 0.7 |
| 4.5 | 3.2 | 0.4 | 1.3 |
| 2.1 | -0.9 | 0.2 | 0.7 |
| 0.0 | -10.4 | -3.2 | 0.6 |
| 3.0 | -0.7 | -0.9 | 0.9 |
| 1.8 | -16.2 | -2.9 | -0.2 |

8-15 model points

Model info

Tracking Range (mm): 20.0
oAB (mm): 0.1
Uncertainty (%): 13.9

Rigid Body (mm): 1.5
collinearity (deg): 15.0
Fiducial Spacing (mm): 18.0

Images
Acquired: 318  Expected: 540
Exposed: 19.4  Expected: 32.9

Tracking parameters
Phase triggered dataset acquisition

- First image – **mid respiratory phase**
- 9 random pairs
- Analysis of current model before triggering 3 additional image pairs at the **required respiratory phase**

- Easier to get an **optimal model** – less user dependent
  - > 85% coverage
  - Well distributed model points
  - Low correlation error
Movie Mode (video)
Comet graphs (video)
The internal target position can be extracted based on gold markers or large/dense tumors visible on 2 cameras or just 1 camera.
1-view tracking

- Tumors visible in only 1 projection image
- The component of motion in the image plane is tracked
- Partial ITV expansion in the un-tracked direction

✅ Sup-Inf motion is tracked
With 1-view tracking is possible to track relatively small targets.

GTV dimensions = 9 x 9 x 9 mm³
Does patient have a fiducial?

**YES**
- Synchrony motion tracking
  - Contour GTV on breath hold CT scan
  - Create PTV by expanding the GTV (2-5 mm)

**NO**
- LOT to determine tracking method
  - 2-views
    - Contour GTV on FB or BH scan
    - PTV = GTV + margin
  - 1-view
    - Contour primary and secondary GTVs on inhale & exhale scans
    - ITV=projection of target motion in the un-tracked direction
    - PTV = ITV+margin use larger margin in the un-tracked plane
  - 0-view
    - Contour ITV on 4DCT scan
    - ITV = PTV +margins use at least 5 mm**

Dynamic tracking
Tracking accuracy

- Calculated the difference between predicted and actual target position
- Mean error $< 0.3 \text{ mm}$
- Intra-fraction error $< 2.5 \text{ mm}$ for respiratory amplitudes up to 2 cm

- Tracking compensated for both intra-fraction motion and for inter-fraction baselines shifts
- Tracking accuracy in phantoms $< 0.95 \text{ mm}$
Tracking with the Vero Gimbals System

- External marker position detected by IR camera
- Internal target position from two stereo kV imager in fluoro mode

- Tracking based on IR breathing signal and correlation model
- Gimbals system – Pan & tilt motion of the treatment beam
- It can quickly steer beam to track tumor motion
- Total system latency is 40 ms
- Marker & marker-less Dynamic Tumor tracking & Gating
Conclusion

- CyberKnife Synchrony enables to synchronize respiratory-induced target motion with radiation delivery
- Correlation model between the position of the internal target and the position of external markers (LED)
- The robot position is continuously re-adjusted to follow the moving target
- Marker & marker-less dynamic tracking
- Clinically implemented for over 10 years
- Tracking accuracy in phantoms < 0.95 mm
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