Gated Radiotherapy for Lung Cancer

Steve B. Jiang, Ph.D.
Depart Of Radiation Oncology
University of California San Diego
sbjiang@ucsd.edu
radonc.ucsd.edu/Research/CART

Two Types of Gating

- Internal gating (fluoroscopic gating)
  - Use internal tumor motion surrogates such as implanted fiducial markers to indicate tumor position
  - Mitsubishi/Hokkaido RTRT system

- External gating (optical gating)
  - Use external respiratory surrogates such as abdominal surface to derive tumor position
  - Varian RPM system

Varian RPM System

Tumor Home Position and Instant Position

Lung tumor motion is both intra- and inter-fraction motion

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Treatment Time</th>
</tr>
</thead>
</table>

Accurate External Gating

- During treatment simulation, the reference home position should be accurately measured, using techniques such as 4D CT.
- During treatment planning, the patient and tumor geometry at the reference home position should be used.
- During patient setup, the tumor daily home position should be matched to the reference home position.
- During the treatment delivery, the tumor home position should be maintained the same.


Patient Breath Coaching

- To achieve regular and stable breathing pattern
- Audio instruction
- Visual feedback
A Breath Coaching Protocol

Moving Objects during CT – A Phantom Study

Motion Artifacts

CT Simulation for Gated Lung Cancer RT

4DCT Scan of A Phantom

Patient Setup for Gated Lung Cancer RT
Patient Setup For Gated Lung Cancer RT

- Room laser/skin tattoos


---

Patient Setup For Gated Lung Cancer RT

- X-ray images of bony structure

---

Inter- and Intra-fraction Motion of Lung Tumor

5D tumor traces on different weeks

Courtesy of Lei Dong

---

Patient Setup For Gated Lung Cancer RT

---

On-line Treatment Verification

- Based on kV imager

- Based on MV imager

---

Cine EPID for Lung Tx Verification using ANN

- Before treatment
  - Generate simulated EPID images using CT data for each beam and with various possible positional errors
  - Train ANN using the simulated EPID images to recognize two classes: tumor within/without the beam aperture

- During treatment
  - Apply the trained network to cine EPID images to see if the tumor is inside the beam

- Preliminary results
  - 6 patients, 4-5 fractions each
  - 95% accuracy

---
Mitsubishi/Hokkaido RTRT System

- 4 sets diagnostic X-ray systems
- Motion tracking software
- Carbon fiber couch
- 2 mm gold marker inside/near tumor
- 1 mm detection accuracy
- 0.033 s time delay

Mitsubishi/Hokkaido RTRT System (Screen Capture)

Multiple Hypothesis Tracking

Implantation of Fiducial Markers

Lung Tumor Tracking without Markers

Direct Tracking of Lung Tumor Mass

- Multiple Template Tracking
  - Cui, Dy, Sharp, Alexander, and Jiang

- Active Shape Model Tracking
  - Xu, Hamilton, Schowengerdt, and Jiang

- Optical Flow Tracking
  - Xu, Hamilton, Schowengerdt, Alexander, and Jiang
Indirect Fluoroscopic Tracking

- **Issues with direct tracking**
  - Directly tracking of the tumor sometimes is impossible due to poor image quality and low target contrast.
  - Common tracking methods used in computer vision often fail since tumor has no color, no texture, and often no clear shape.
- **We proposed an indirect tracking approach**
  - Tracking invisible tumor by tracking visible surrogate features.

**Algorithm for Indirect Tracking (1)**

- **Choose surrogate ROIs**
  - Red tumor position
  - Green two ROIs

**Algorithm for Indirect Tracking (2)**

- **Map each ROI frame into 3D PCA space**
  - Each ROI frame is represented as $(x_1, x_2, x_3)$

**Algorithm for Indirect Tracking (3)**

- **Pre-treatment training**
  - Regression between tumor location $(y_1, y_2)$ and the 3D PCA coordinates of each ROI.
- **During treatment**
  - Prediction based on the regression.

**Indirect Fluoroscopic Tracking**

- **Indirect Lung Tumor Tracking**
  - **Machine learning techniques**
    - PCA for dimensionality reduction and feature extraction
    - Regression (1-degree, 2-degree, ANN, SVM)
  - **Experiments**
    - Fluoroscopic sequences of 10 lung cancer patients
    - Mean tracking error: $\approx 1.1$ mm
    - Maximum error at 95% confidence level: $2.3$ mm

Gating as A Template Matching Problem

Training:
- Fluoroscopic Images
- Preprocessing (PCA, etc.)
- Reference Template(s)

Treatment:
- Incoming Fluoroscopic Images
- Preprocessing (PCA, etc.)
- Template Matching & Scoring

Gating as A Classification Problem

Training:
- Incoming Fluoroscopic Images
- Preprocessing (PCA, etc.)
- Labeling
- Trained Classifier

Treatment:
- Incoming Fluoroscopic Images
- Preprocessing (PCA, etc.)
- Classification

Classification methods tested
- Support Vector Machines (SVM)
  - Cui, Dy, Alexander, and Jiang, Phys Med Biol. 2008 (in print)
- Artificial Neural Network (ANN)
  - Lin, Tang, Dy, and Jiang, Phys Med Biol. 2008 (submitted)

Pros and Cons of Each Gating Method

Internal: accurate however expensive
- Carefully implanted multiple fiducial markers
- High cost, invasive, imaging dose

External: less expensive however less accurate
- Low cost, noninvasive, radiation free, easy to implement
- Uncertainties in external/internal correlation

Combine External/Internal Signals

- Hybrid gating
  - Drive tumor positions from external surrogates
  - Low frequency updating of external/internal correlation

Future Gated Lung Cancer RT

- Respiratory surrogates → gating signals
  - Better respiratory signals
  - Real-time 3D surface imaging
- X-ray images → update internal/external correlation
  - Only taken when necessary
  - Derive tumor positions using machine learning methods
  - Correlation based on sophisticated lung models
- Breath coaching
  - Required for some patients to ensure sufficient accuracy and efficiency
- Cine EPID based on-line treatment verification
  - Very high dose rate
  - “Snapshot” therapy
Future Gated Lung Cancer RT

- Gating should be applied to every lung cancer RT
- Nothing to lose when motion is small
  - ~ 100% duty cycle
- Motion may change later in the treatment course
- Gating can be used to monitor patient motion

Which of the following CT simulation technique is best suited for gated treatment of lung cancer patients?

- 0% 1. 4D CT scan
- 0% 2. Breath hold CT scan
- 0% 3. Slow CT scan
- 0% 4. Free breathing CT scan
- 0% 5. None of the above

References
Jiang SB
Radiotherapy of mobile tumors

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy

Answer: 1 – 4D CT scan

Which of the following statement is NOT true for gating based on external surrogates (external gating)?

- 0% 1. External gating is non-invasive
- 0% 2. External gating is relatively easy to implement
- 0% 3. External gating does not require any radiation dose for imaging
- 0% 4. External gating rely on a good and stable correlation between tumor motion and surrogate signal
- 0% 5. The correlation between tumor motion and surrogate signal does not change intra- and inter-fractionally for any lung cancer patients

References
Jiang SB
Radiotherapy of mobile tumors

Which of the following statement is NOT true for gating based on implanted fiducial markers (internal gating)?

- 0% 1. Internal gating is less accurate than external gating
- 0% 2. Internal gating is more invasive than external gating
- 0% 3. Marker implantation in lung may cause pneumothorax
- 0% 4. High imaging dose may be required for the fluoroscopic tracking of the implanted fiducial markers
- 0% 5. The combination of external and internal gating may reduce the imaging dose

References
Jiang SB
Radiotherapy of mobile tumors

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy
Answer: 1 – Internal gating is less accurate than external gating

References

Jiang SB
Radiotherapy of mobile tumors

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy

Acknowledgement