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

Shooting A Target by Looking in The Mirror

Gating based on External Surrogates

Tumor Home Position and Instant Position

Kanoulas, Aalam, Shuyu, Berbeco, Nishioka, Shirato, and Jiang

Wu, Zhao, Berbeco, Nishioka, Shirato, Jiang

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

(Jiang, Technical aspects of image-guided respiration-gated radiation therapy, Med Dosim. 31(2):141-51, 2006)

**Patient Breath Coaching**

- To achieve regular and stable breathing pattern
  - Audio instruction
  - Visual feedback

**A Breath Coaching Protocol**

- Free breathing CT scan
- Breath-hold CT scan
  - Voluntary breath hold
  - Active breathing control
- Slow CT scan
  - 4 seconds per slice in axial mode
- 4D CT scan
  - 3D scans at multiple phases


**CT Simulation for Gated Lung Cancer RT**

- Free breathing CT scan
- Breath-hold CT scan
- Slow CT scan
  - 4 seconds per slice in axial mode
- 4D CT scan
  - 3D scans at multiple phases

**Patient Setup for Gated Lung Cancer RT**

- Room laser/skin tattoos
- X-ray image of bony structure
- 3D/4D cone beam CT
Patient Setup For Gated Lung Cancer RT

- Room laser/skin tattoos

Inter- and Intra-fraction Motion of Lung Tumor

- 3D tumor traces on different weeks

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
Gating based on Implanted Fiducial Markers

Mitsubishi/Hokkaido RTRT System

Calypso 4D Localization System

Implantation of Fiducial Markers

How to Track a Moving Tumor?

Multiple Template Tracking

Active Shape Model Tracking

Optical Flow Tracking

Direct Lung Tumor Tracking w/o Markers

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.


Indirect Fluoroscopic Tracking
Diaphragm as an Internal Surrogate

\[ f(x) = x^2 \sum \delta(y) \]

Mean error: 1 mm
Maximum error (e95): 2 mm

Cervino, Chao, Sandhu, and Jiang

Diaphragm Does Not Always Work

Gating Is A Two-Class Classification Problem

Training:
- Fluoroscopic images
- Preprocessing
- Labeling
- Trained Classifier

Classification Problem:
- Gating
- Signal

Gating as A Classification Problem

Training:
- Fluoroscopic Images
- Preprocessing
- Template Matching
- Linear classifier

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

ANN based Gating

Cui, Dy, Alexander, and Jiang,

Lin, Tong, Dy, and Jiang,

Berbeco, Mostafavi, Sharp, and Jiang,

Cui, Dy, Sharp, and Jiang,

Template Matching Methods

Support Vector Machines (SVM)

Artificial Neural Network (ANN)
Hybrid Gating

- X-ray (Only when necessary)
- Surface Tracking Camera (Always on)

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

Answer: 1 – 4D CT scan

References

Jiang SB
Radiotherapy of mobile tumors

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

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

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 reply 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
Answer: 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

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

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

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