Gated Radiotherapy for Lung Cancer

Steve B. Jiang, Ph.D.

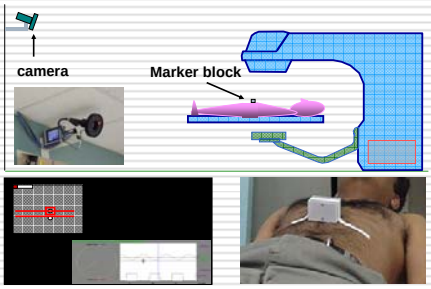
Depart Of Radiation Oncology
University of California San Diego

sbjiang@ucsd.edu
radonc.ucsd.edu/Research/CART

Two Types of Gating

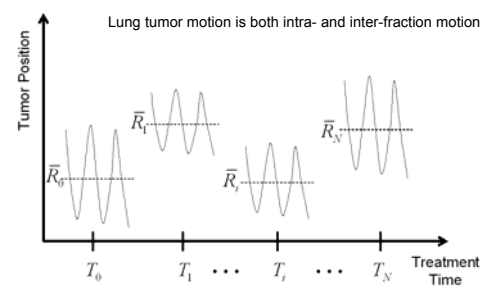
- **Internal gating (fluoroscopic gating)**
  - Use internal tumor motion surrogates such as implanted fiducial markers to indicate tumor position
  - Mitsubishi/Hokkaido RTRT system
- **External gating (optical gating)**
  - Use external respiratory surrogates such as abdominal surface to derive tumor position
  - Varian RPM system

Varian RPM System



Photos in lower row courtesy of P Keall

Tumor Home Position and Instant Position



Accurate External Gating

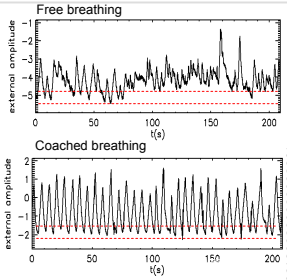
- During treatment simulation, the reference home position should be accurately measured, using techniques such as 4D CT.
- During treatment planning, the patient and tumor geometry at the reference home position should be used.
- During patient setup, the tumor daily home position should be matched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

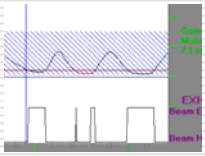
Jiang, Technical aspects of image-guided respiration-gated radiation therapy, *Med Dosim*. 31(2):141-51, 2006.

Patient Breath Coaching

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

A Breath Coaching Protocol





Neicu, Berbeco, Wolfgang, and Jiang, *Phys Med Biol.* 51(3):617-636, 2006.

Moving Objects during CT – A Phantom Study

Video courtesy of George T.Y. Chen

Chen, Kung, and Beaudette, *Semin Radiat Oncol.* 14(1):19-26, 2004.

Motion Artifacts

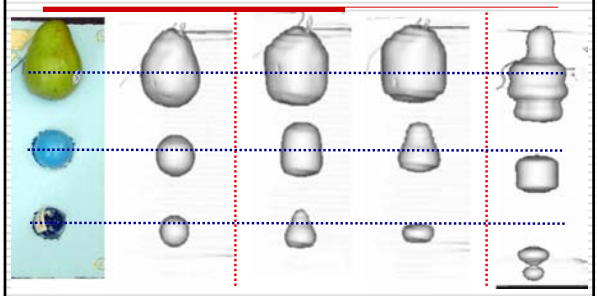


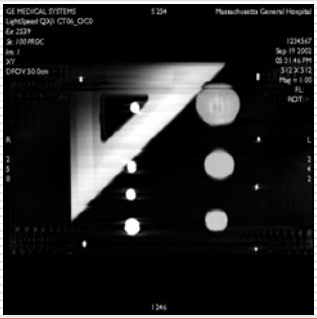
Photo **Static** **Moving / HS mode** **HQ**

Courtesy of George Chen

CT Simulation for Gated Lung Cancer RT

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

4DCT Scan of A Phantom



Courtesy of Eike Rietzel and George T.Y. Chen

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

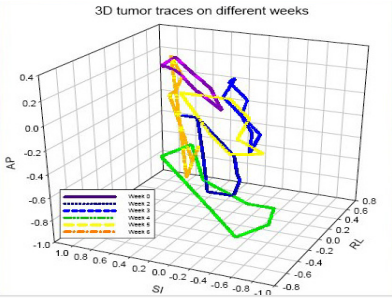
- Room laser/skin tattoos

Nelson, Starkschall, Balter, Morice, Stevens, Chang, *Int J Radiat Oncol Biol Phys*, 67(3):915-23, 2007.

Patient Setup For Gated Lung Cancer RT

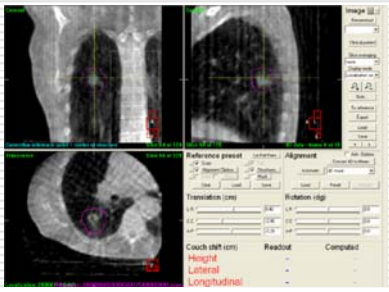
- X-ray images of bony structure

Inter- and Intra-fraction Motion of Lung Tumor



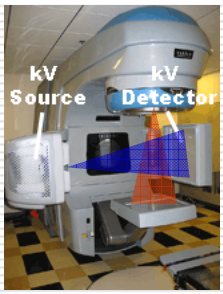
Courtesy of Lei Dong

Patient Setup For Gated Lung Cancer RT



M van Herk, L Zijp, P Remeijer, J Wolthaus, JJ Sonke, ICCR 2007.

On-line Treatment Verification



- Based on MV imager
- Based on kV imager

Cine EPID for Lung Tx Verification using ANN

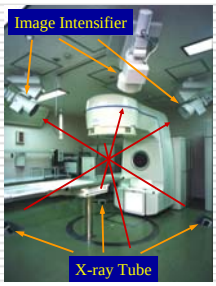
- **Before treatment**
  - Generate simulated EPID images using CT data for each beam and with various possible positional errors
  - Train ANN using the simulated EPID images to recognize two classes: tumor within/without the beam aperture

- **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

TH-D-AUD C-9 Thursday 12:30:00 PM - 2:20:00 PM Room: Aud-C

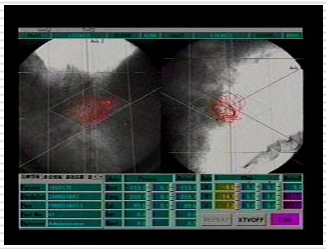
Mitsubishi/Hokkaido RTRT System



- 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

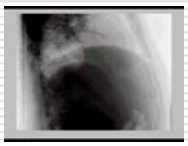
Shirato et al *IJROBP* 48:435-442, 2000

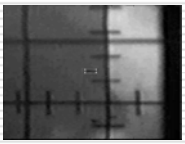
Mitsubishi/Hokkaido RTRT System (Screen Capture)



Video courtesy of H Shirato

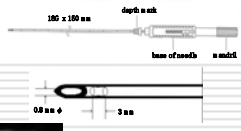
Multiple Hypothesis Tracking



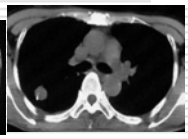


Tang, Sharp, and Jiang, *Phys Med Biol*, 52:4081-4098, 2007

Implantation of Fiducial Markers

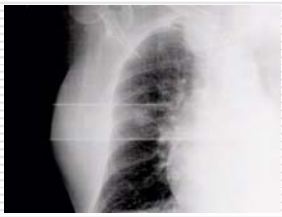


CT guided implantation



US guided implantation

Lung Tumor Tracking without Markers



Direct Tracking of Lung Tumor Mass

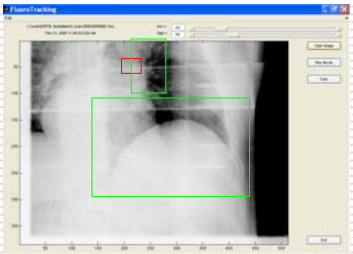
- **Multiple Template Tracking**
  - Cui, Dy, Sharp, Alexander, and Jiang *Phys Med Biol*, 52(20):6229-6242, 2007.
- **Active Shape Model Tracking**
  - Xu, Hamilton, Schowengerdt, and Jiang *Phys Med Biol*, 52(17):5277-5293, 2007.
- **Optical Flow Tracking**
  - Xu, Hamilton, Schowengerdt, Alexander, and Jiang *Med Phys*, 2008 (in print)

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 fails 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**

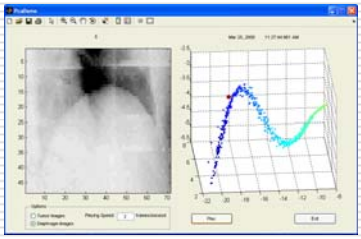


Red
tumor position

Green
two ROIs

Algorithm for Indirect Tracking (2)

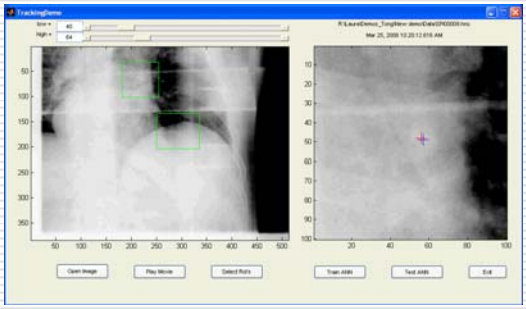
- **Map each ROI frame into 3D PCA space**
  - Each ROI frame is represented as (x1, x2, x3)



Algorithm for Indirect Tracking (3)

- **Pre-treatment training**
  - Regression between tumor location (y1, y2) 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: ~1.1 mm
  - Maximum error at 95% confidence level: 2.3 mm

TU-C-351-9 Tuesday 10:00:00 AM - 12:00:00 PM Room: 351

Lin, Cervino, Tang, Vasconcelos, and Jiang, Fluoroscopic Tumor Tracking for Image Guided Lung Cancer Radiotherapy, *Phys Med Biol* 2008 (submitted)

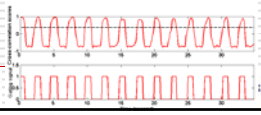
Gating as A Template Matching Problem

Training: Training Fluoroscopic Images → Preprocessing (PCA, etc) → Template Building → Reference Template(s)

Treatment: Incoming Fluoroscopic Images → Preprocessing (PCA, etc) → Template Matching & Scoring → Gating Signal

Berbeco, Mostafavi, Sharp, and Jiang, *Phys Med Biol.* 50(19): 4481-4490, 2005.

Cui, Dy, Sharp, Alexander, Jiang, *Phys Med Biol.* 52(3):741-55, 2007.



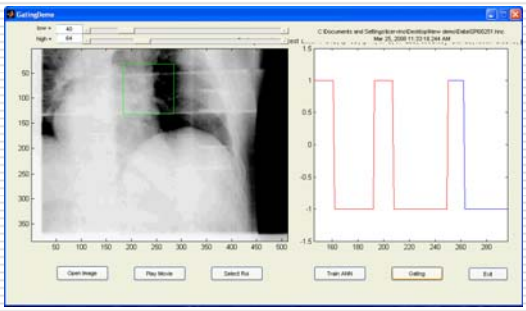
Gating as A Classification Problem

Training: Training Fluoroscopic Images → Preprocessing (PCA, etc) → Labeling → Trained Classifier

Treatment: Incoming Fluoroscopic Images → Preprocessing (PCA, etc) → Classification → Gating Signal

- **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)

ANN based Gating



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

Answer: 1 – 4D CT scan

References

Jiang SB
Radiotherapy of mobile tumors
Semin Radiat Oncol, 2006. 16(4): p. 239-48.

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

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
Semin Radiat Oncol, 2006. 16(4): p. 239-48.

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

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
***Semin Radiat Oncol*, 2006. 16(4): p. 239-48.**

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

Acknowledgement