

Fluoroscopic imaging for IRGT

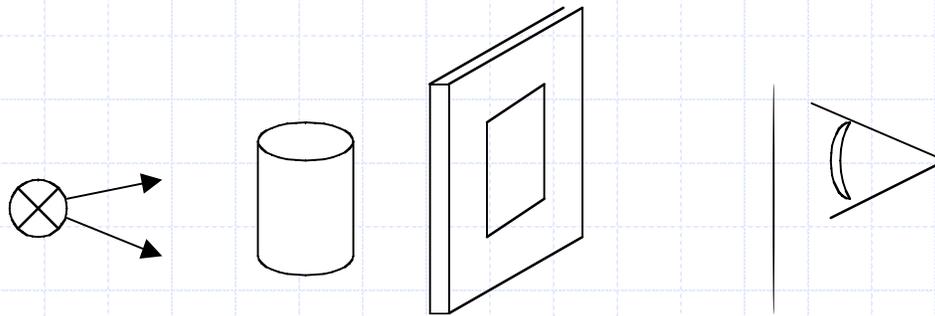
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Fluoroscopy is continuous x-ray imaging

◆ Source object screen viewer



Imaging technique

- ◆ Conventional fluoroscopic imaging is done at tube voltages between 60 kV and 120 kV
- ◆ Typical tube currents limited to approximately 100 mA
- ◆ The tube spectrum is typically filtered by 2 - 4 mm Al or its equivalent

Different fluoroscopic systems

- ◆ Traditional - the observer looks directly at the phosphor screen
- ◆ optical video - the viewer is replaced by a system of mirrors and lenses observed by a video camera
- ◆ X-ray Image Intensifier (XII) - the viewer is replaced by a focusing photomultiplier tube observed by a video camera
- ◆ Flat-panel digital - the phosphor screen is replaced by, e.g., an aSi digital detector

optical video

- ◆ Video frame rate (30 fps)
- ◆ Limited contrast due to veiling glare
- ◆ Limited acceptance by the lens resulting in a quantum sink between the screen and the camera. Noise is detector rather than source-limited
- ◆ A little radial distortion from the lens

X-ray Image Intensifier (XII)

- ◆ Video frame rate
- ◆ Much higher acceptance than CCD optics, resulting in noise limited by incident x-ray flux
- ◆ Limited contrast due to veiling glare
- ◆ Radial and pin-cushion distortion that varies with position relative to earth's magnetic field

Flat-panel detector

- ◆ High geometrical acceptance
- ◆ No distortion
- ◆ High dynamic range/contrast
- ◆ Frame rate limited by digital readout, which depends on number of pixels
- ◆ Only now getting 10+ frames per second

Fluoroscopic modes

- ◆ Continuous beam; continuous readout
- ◆ Continuous beam; pulsed readout
- ◆ Pulsed beam; continuous readout
- ◆ Pulsed beam; pulsed readout

Typical systems for IGRT

- ◆ C-arm - the ubiquitous surgical image guidance device
- ◆ Simulator
- ◆ Customized patient positioning/tracking system
 - Room-mounted (Hokkaido)
 - Gantry-mounted (MGH IRIS)
- ◆ Varian OBI (On-board imaging)

Three uses of fluoroscopy

- ◆ Pretreatment motion assessment
- ◆ Setup of gating and tracking parameters
- ◆ Intra-fraction respiratory tracking and compensation

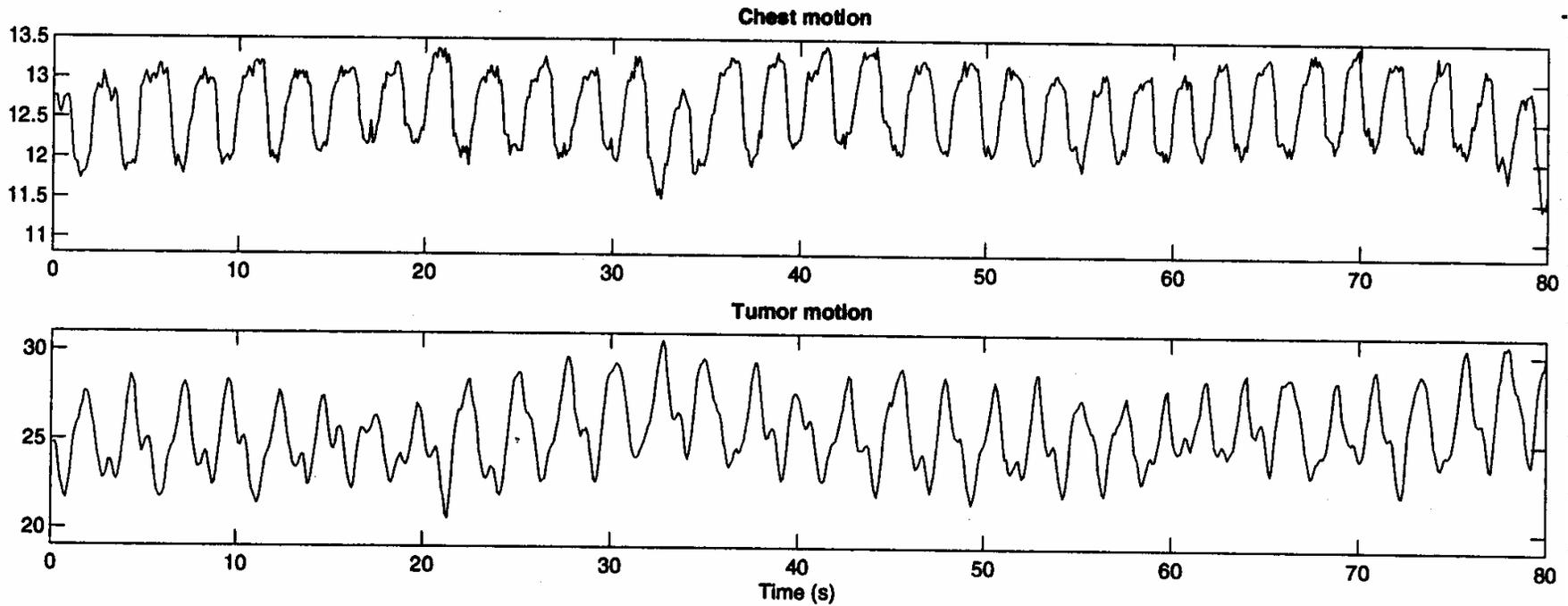
Pretreatment assessment

- ◆ Set beam gating parameters (Vedam, Med Phys 28, 2001)
- ◆ Test breathing prediction algorithms (Isaacson, Med Phys 32, 2005)
- ◆ Analyze tumor/surrogate correlations (Hosiak IJROBP 60, 2004, Isaacson, Med Phys 32, 2005, etc)

Pre-treatment assessment

QuickTime™ and a
Video decompressor
are needed to see this picture.

Tumor/chest correlation observed fluoroscopically (Murphy et al, CARS 2002)



Treatment setup

- ◆ Minohara et al (IJROBP 47, 2000) coordinated an external trigger signal with tumor motion during pre-treatment fluoroscopy, then used the external signal to trigger a beam gate.

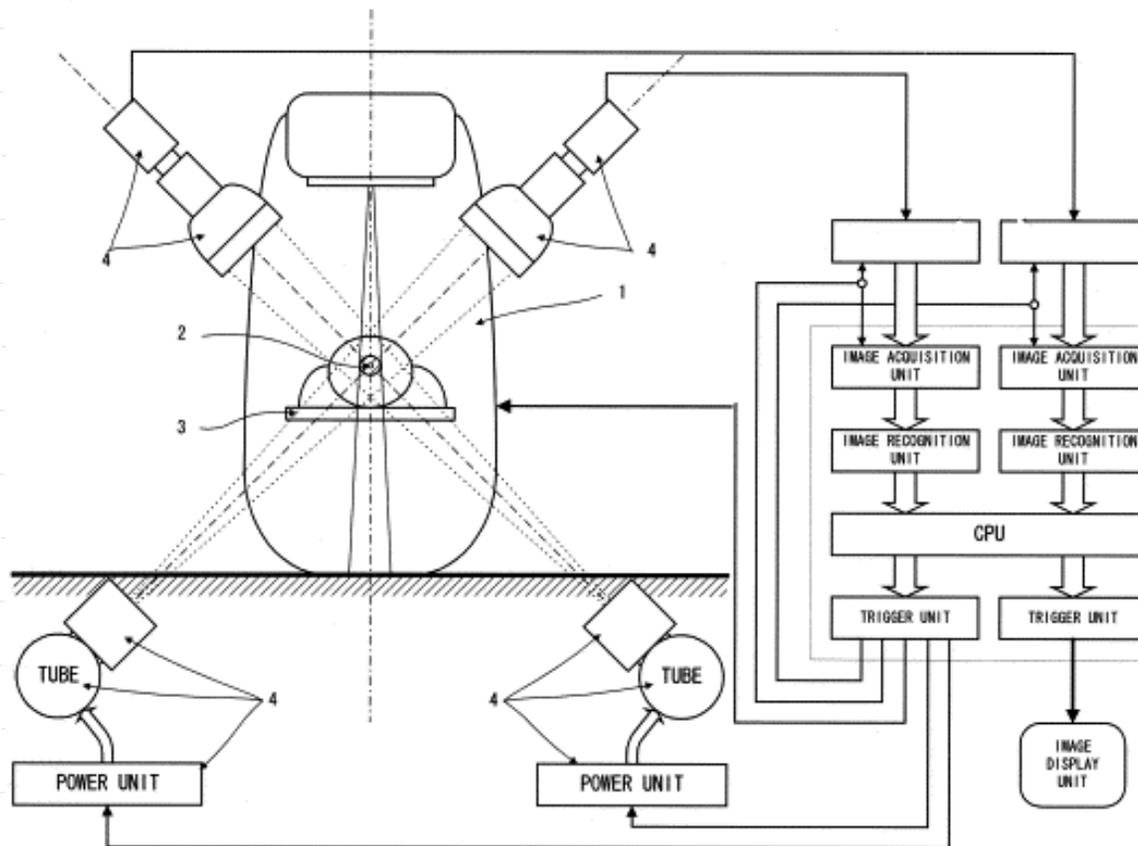
Intra-fraction tracking

- ◆ Beam adaptation to target movement involves some lag time, which requires motion prediction
- ◆ Random motion is unpredictable
- ◆ Slow systematic motion doesn't require fluoroscopy
- ◆ Therefore intra-fraction fluoroscopic tracking is only relevant to tracking respiratory and cardiac motion

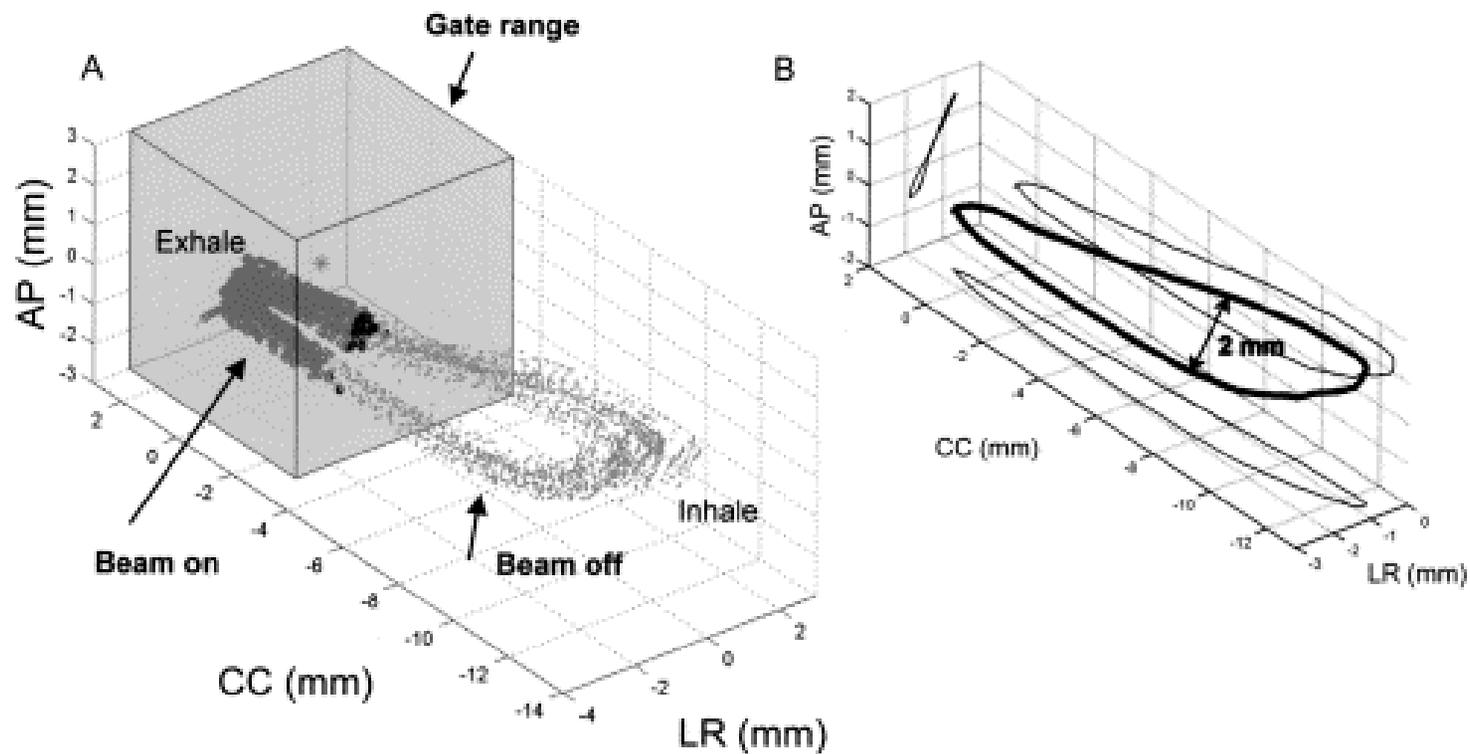
In-room fluoroscopy

- ◆ For intra-fraction tracking it is important that the treatment beam not interfere with the images
- ◆ Steve Jiang at MGH has tested fluoroscopic imaging of fiducials with the beam on and found fiducial detection is not impaired

In-room fluoroscopy at Hokkaido University Hospital (Shirato, IJROBP 40, 2000)



Trajectory measurement for gating (Seppenwoolde, IJROBP 53, 822, 2002)



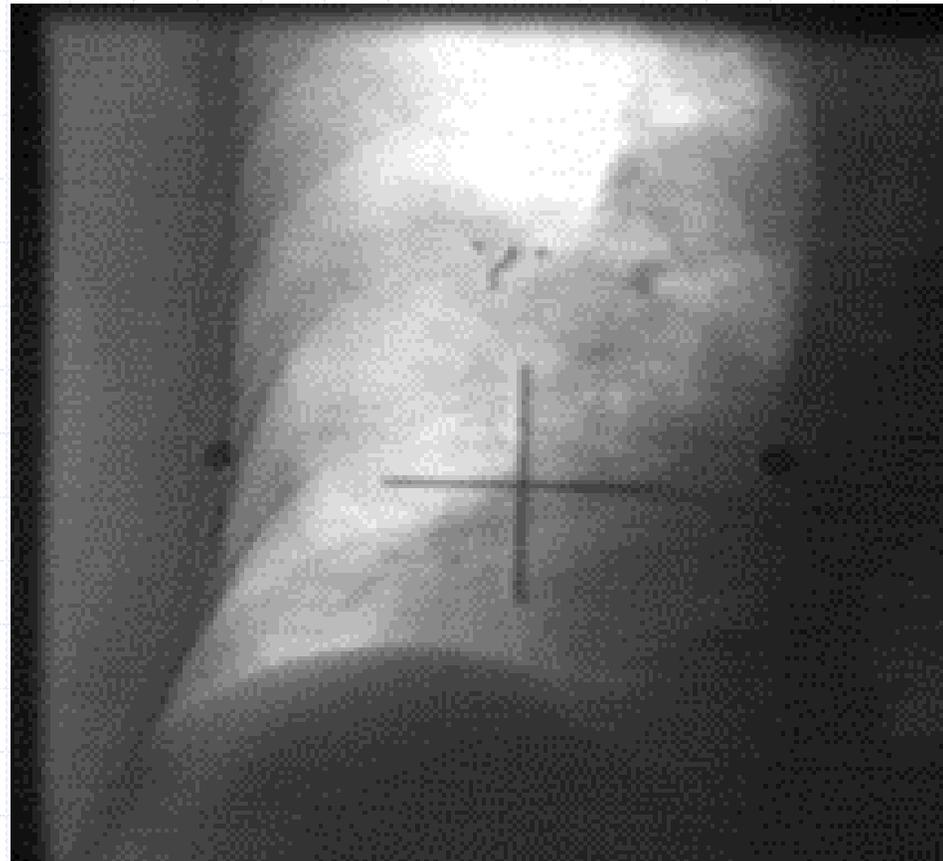
Technical issues in fluoroscopic tracking

- ◆ Locating the target in real time
- ◆ Keeping track of the target
- ◆ Keeping up with the target
- ◆ Managing the imaging dose

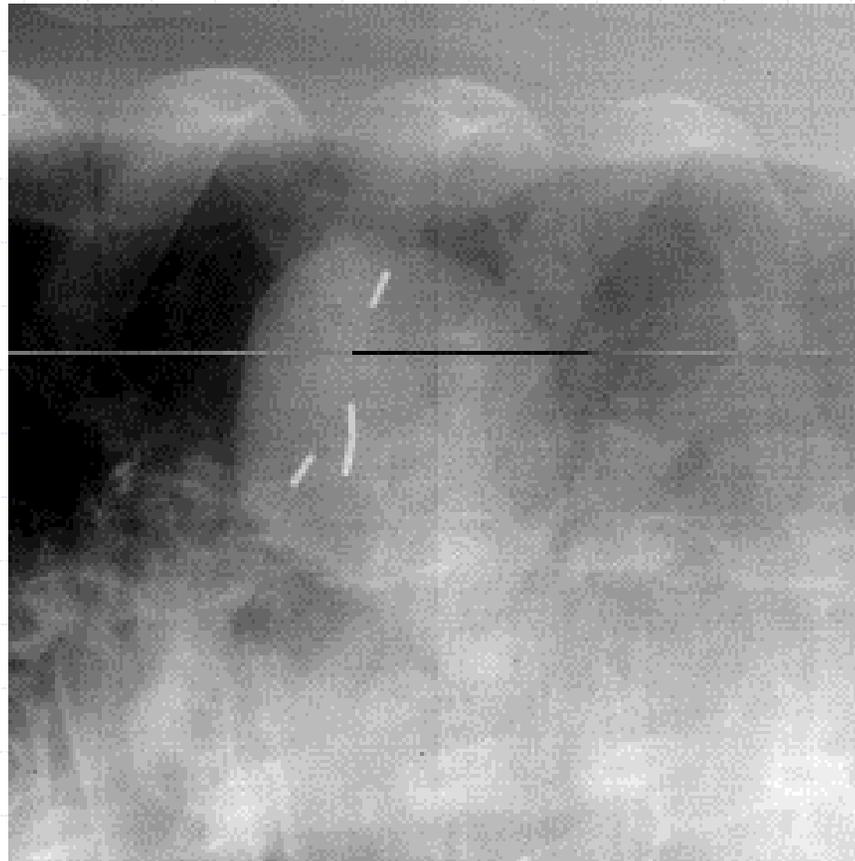
Locating the target

- ◆ Anatomical surrogate - e.g., the diaphragm
- ◆ Artificial internal fiducial implanted in the tumor
- ◆ The tumor itself

A fluoro image of fiducials in a lung tumor



A radiographic image of a lung tumor



Finding the target

- ◆ Requires automatic image processing at 30 frames per second
- ◆ Fiducial position extraction
- ◆ Tumor image tracking

Tumor tracking via template matching

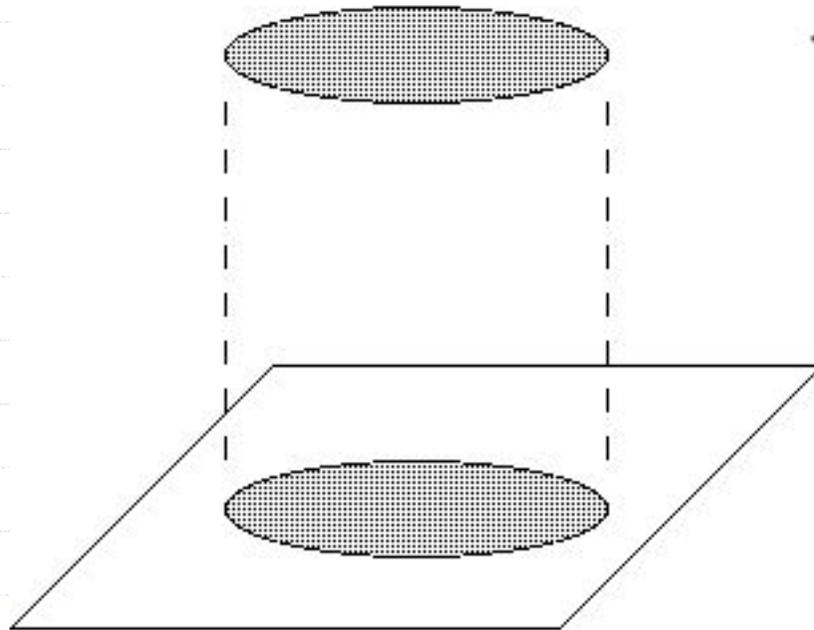
(Berbeco et al (Phys Med Biol 50, 2005))

- ◆ A pre-treatment fluoro study is acquired
- ◆ End-exhale is identified by measuring the transmitted x-ray intensity as a function of breathing phase
- ◆ Fluoro frames at end-exhale are extracted and enhanced to produce a template (matched filter) of the tumor position at end-exhale
- ◆ During treatment, realtime fluoro images are convolved with the template to find end-exhale - at which time the gate is triggered

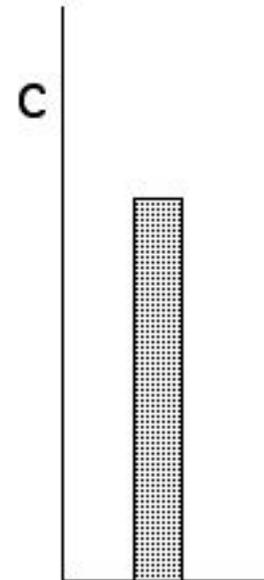
Matched filter tumor tracking

Tumor image A

$$C = \frac{\int A(x) B(x) dx}{\sqrt{[\int A(x)^2 \int B(x)^2]}}$$



Matched filter
template image B



Real-time convolution

- ◆ Image correlation must be done at 30 fps
- ◆ If the image and the template are normalized then Pearson's correlation coefficient $(A \cdot B) / (\sqrt{A^2} \sqrt{B^2})$ reduces to $A - B$, which can be computed rapidly

Keeping track of the target

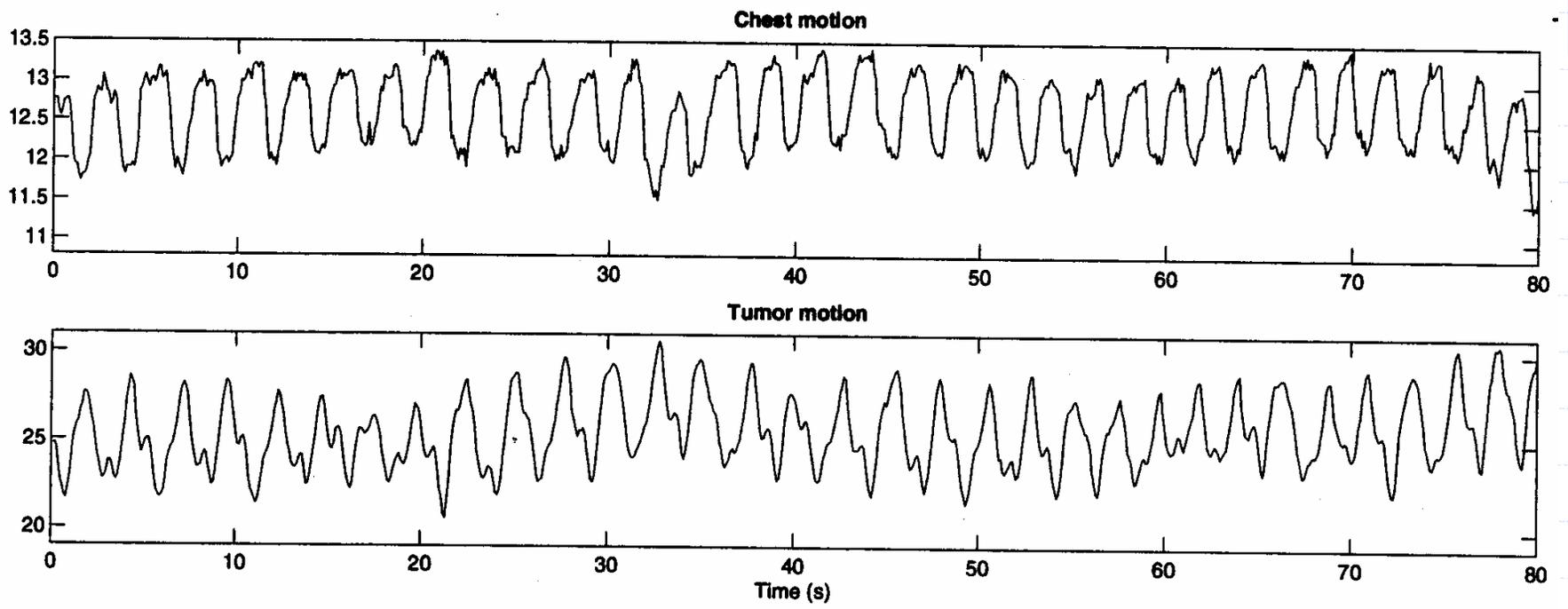
- ◆ Sharp et al (Phys Med Biol 49, 2004) have developed algorithms to monitor the stream of fiducial position data extracted from the Hokkaido fluoroscopic system. The algorithms detect inconsistencies in the trajectory that indicate a possible loss of target position.

Tracking fault detection in the Hokkaido system (Sharp et al)

- ◆ For each frame get
 - Pattern recognition score - strength of fiducial detection
 - Stereoscopic distance-to-intersection of two projections
 - Velocity of the tumor target
- ◆ These three indicators are used as input to a neural network classifier to distinguish valid tumor trajectories from loss of target

Keeping up with the target

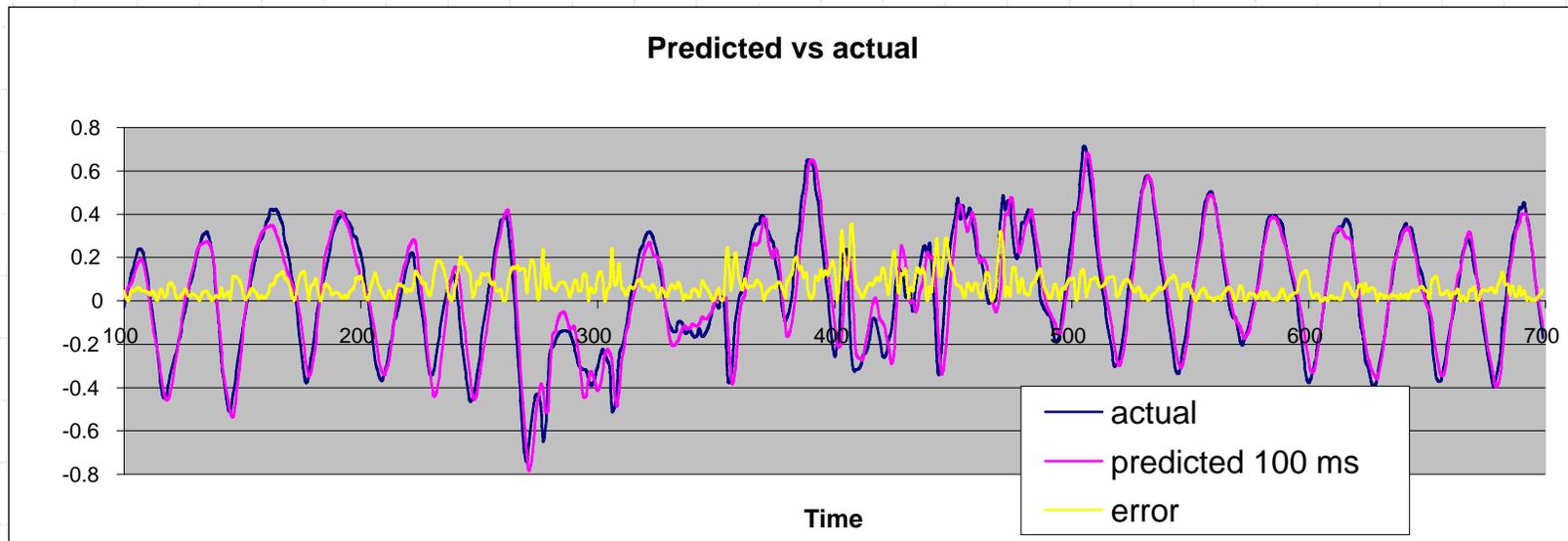
- ◆ No tracking system responds instantaneously
- ◆ Target position data must accommodate system lag time via prediction
- ◆ Lag times can be 50 - 300 ms
- ◆ Breathing can be very irregular and surprisingly hard to predict



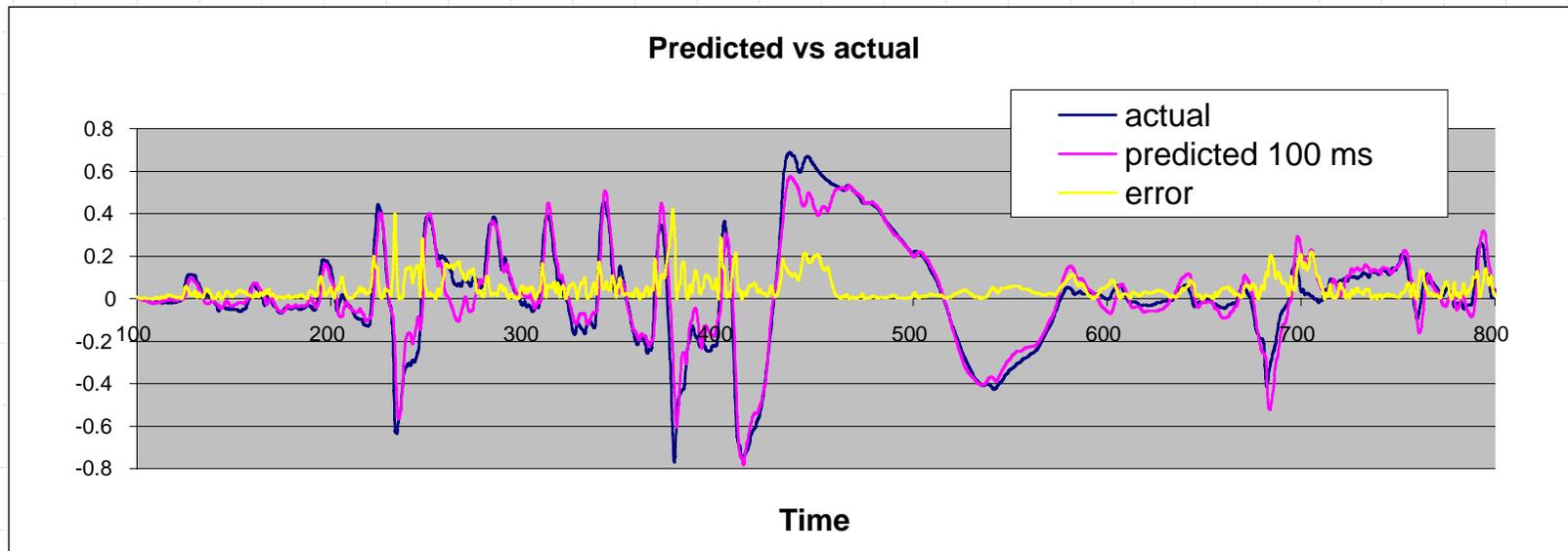
Following the target

- ◆ Intra-fraction tracking methods often use periodic function models of breathing to follow and predict the target position.
- ◆ Many patients with regular breathing will experience transient irregularities.
- ◆ Some patients are observed to breathe in a highly irregular manner.
- ◆ Anomalous breathing cannot be tracked with periodic functions or linear models
- ◆ Non-linear neural networks can mimic irregular breathing

Transients tracked with a nonlinear neural network (Murphy and Dieterich 2006)



Chaotic breathing tracked with a nonlinear neural network (Murphy and Dieterich 2006)



Dose from fluoroscopy

- ◆ A typical C-arm with an XII delivers about 2 cGy per minute entrance skin dose for the thorax
- ◆ At 30 frames per second the Hokkaido system delivers 0.3 to 1.3 cGy/min to the thorax, depending on kV
- ◆ A conventional RT fraction is about 2 minutes; an IMRT fraction can be >10 minutes; radiosurgical fractions can be > 30 minutes
- ◆ We will review these kinds of dose issues in a later lecture

Dose management

- ◆ Collimation to reduce the field of exposure
- ◆ Pulsed fluoroscopy to reduce the fluence
- ◆ The Hokkaido system is now equipped for duty cycles of 2, 5, 10, 15, and 30 fluoro frames per second. Lower frame rates are used for longer IMRT fractions. (Shirato, IJROBP 60, 2004)

Summary

- ◆ Fluoroscopic imaging can be used to assess and compensate for respiratory motion
- ◆ Assessment can involve testing prediction, correlation, and gating algorithms
- ◆ Realtime compensation during treatment requires fast, robust image analysis, fault tolerance, and lag time compensation