IMAGE GUIDED RADIATION THERAPY (IGRT)

Manish Kakar, PhD
OUTLINE

- What is IGRT?
- Imaging Devices
- Errors and Margins
- Case Study - Respiratory Motion
  - Margin reduction
  - Advanced Methods (State of the Art in IGRT)
    - Intelligent Systems
    - 4DCT & Adaptive Radiation Therapy
WHAT IS IGRT?

- Image Guided RT (IGRT) is the use of imaging to guide Radiation Therapy for:
  - Treatment decisions (How/whether to treat)
  - Delineation (ROI)
  - Positioning
  - Assessment of the outcome (treatment Verification)
IMAGING DEVICES
**EPID**

- Electronic Portal Imaging Device (EPID):
  - Name given to Digital flat panel devices.
  - Metal plate + phosphor screen
  - Treatment x-rays cause the phosphor to glow
  - resulting light is detected by an array of photodiodes
- Ex. Verification (IMRT);
FLOROSCOPY

- A fluoroscope consists
  - X-ray source + fluorescent screen
  - patient is placed in between these
- Modern fluoroscope
  - ccd camera (recording and playing on a monitor)
FLOROSCOPY - APPLICATIONS

- **Usage**
  - Real-time moving images of the internal structures of a patient
- **Disadvantage**
  - Pose a potential health risk to the patient
  - Long exposure times
ULTRASOUND

- Ultrasounds – Cyclic pressure (created by sound waves) at frequencies greater than human hearing (20 KHz)
- In medicine – Ultrasound sonography
  - Hand-held probe (Transducer) placed directly over the patient
  - Reflections from pulses recorded and displayed
ULTRASOUND - APPLICATION

- Usually used for determining
  - Localization of the target and
  - Depth of the target
- Ex: Prostate thickness and depth of rectum – measured by Ultrasound for determining dose to prostate and rectum.
MRI

- Human body is composed of water molecules (protons)
- Placed inside a powerful magnetic field protons align with the direction of the magnetic field
- Additional RF electromagnetic field is briefly turned on causing the protons to absorb some of its energy
- When this field is turned off protons release this energy at radio frequency which is then detected by the scanner
- Position of protons is determined by applying additional magnetic field (on and off) during scanning allowing image of the body to build up.
MRI - APPLICATIONS

- Used for:
  - Improved soft tissue visualization
    - Better target delineation
- Disadvantages
  - Geometric Distortion:
    - Variation in Magnetic field - can result in errors in treatment planning
CBCT provides faster volumetric imaging
OPTICAL TRACKING

- RPM System – Real-time position management system by Varian
  - Reflective marker block placed on the xyphoid region of the patient.
  - Marker movement recorded and sampled via infrared camera into a respiratory signal.
4DCT

- A 3D CT image
  - Snapshot in time
  - May not represent the true position, volume, shape or trajectory of a moving tumor
- 4DCT - 4\textsuperscript{th} Dimension (TIME)
  - Captures temporal changes from moving anatomy
VIDEO – 4DCT
4DCT - APPLICATIONS

- 4D CT image dataset used for
  - Devising breathing motion model
  - Normally used with 4DCT & Adaptive Radiation Therapy (ART) – Advanced planning and delivery techniques
ERRORS AND TREATMENT MARGINS
IMAGING ERRORS

- Snapshot provided by imaging may not be correct for all stages of treatment
- Sources of error
  - Definition of tumor
  - Setup of the patient
  - Moving anatomy
VOLUME DEFINITIONS

• GTV (Gross Tumor Volume):
  • Gross visible/demonstrable extent of the malignant growth

• CTV (Clinical Tumor Volume):
  • Contains GTV and/or subclinical microscopic malignant tissues to be irradiated

• PTV (Planning Target Volume): CTV plus a margin to account for
  • Internal organ motion
  • Patient setup variations.
  • Patient motion during treatment.

• OAR (Organs at risk): Critical normal tissues whose radiation sensitivity may influence treatment planning/dose prescription Ex. Spinal cord
TUMOR DELINEATION ERRORS

• Sources of error:
  • Interobserver variations (manual delineation)
  • Limited resolution of imaging devices – Partial Volume effect.
• Errors here influences the whole treatment
• Can be improved by Automatic Segmentation
SETUP ERRORS

- Errors due to patient position and orientation from fraction to fraction (interfractional)
- Ca. Gaussian Distributed
- Can be systematic and Random
SYSTEMATIC AND RANDOM ERRORS

• Systematic
  • Originate – from patient planning stage.
  • Obs - Constant across all fractions for a given patient

• Random:
  • Originate - from setup of the patient for a particular treatment fraction
  • Obs - Vary from fractions to fractions for a single patient treatment
INTERNAL ORGAN MOTION

- Moving anatomy effects
  - tumors in thorax and abdominal regions
  - Causes blurring of dose distribution along path of motion
- Ex. : Breathing Motion (Mainly intrafractional)
DISTORTION DUE TO INTERNAL TARGET MOTION

Distorted

Undistorted
CURRENT PRACTICES - MARGINS

- To overcome the effects of errors and uncertainties, margins are included/extended.
CORRECTION STRATEGIES

• Setup errors:
  • **Offline**: Error accumulated through treatment sessions and corrected at the next fraction
    • Good for removal of Systematic errors
  • **Online**: Corrections made at start of each fraction
    • Good for removal of Systematic & Random errors
CORRECTIONS FOR MOVING ANATOMY

- Non Gaussian Distributed (breathing motion)
- Variability from cycle to cycle.
- Corrections are normally made by
  - Large margins
  - Gating, Breath hold, tracking
CASE STUDY – RESPIRATORY MOTION COMPENSATION
RESPIRATORY MOTION

- Respiratory motion effects all tumors in abdomen and thorax
- Target Motion dominant than setup errors (intra-fractional)
- Precise delivery of dose becomes more challenging
  - Tumour under dosage
  - Healthy tissue over dosage
- Solution
  - Adding margins to CTV
- Drawback: Irradiates unnecessary tissue
BREATH HOLD TECHNIQUES

• Voluntary breath holding by patient:
  • Ex. Active Breath Control/Coordinator (ABC)
  • External scissor valve activates breath control
  • Patient controls the switch (pressed – breath hold, released – breath normally)

• Disadvantages:
  • Uncomfortable for patient
BREATH HOLD
GATING

• Selectively treat a moving target by electronically tuning on and off at specified intervals.

• RPM System (Real time position Management System):
  • Infrared Camera
  • Passive marker on Xyphoid region of patient
  • Processing of tracked motion
GATING
EXAMPLE: MARGIN REDUCTION

Conventional  

With gating
DRAWBACKS OF GATING

• External Gating
  • Inaccuracy due to correlation b/w internal motion and marker.

• Internal Gating:
  • Implanted fiducial markers - risk of pneumothorax

• Tracking
  • Direct tumor tracking and targeting techniques required without implanting fiducial markers
TRACKING - CYBERKNIFE
• Linac mounted on a robot manipulator
• 6 degrees of freedom
• Fiducial markers are placed on the chest wall
• Can take several minutes to hrs between treatment
  • Not continuous
ADVANCED METHODS
WHAT IS INTELLIGENCE AND AI?

- The idea of Machine Intelligence refers back to 1936
  - Combination of five components for intelligence: Understanding, Perception, Problem Solving, Reasoning and Learning
- Real Intelligence – What comprises of thought process of humans.
- Artificial Intelligence – Property of machines giving it ability to mimic the human thought process.
Intelligent systems are systems which are capable of learning and making decisions like in humans.

Example:

- Hybrid Intelligent Systems (HIS)
  - ANFIS (Adaptive Neuro Fuzzy Inference System)
ADVANTAGES OF HIS

• Advantages:
  • Adapation to the input
  • Automatically rule extraction from numerical inputs
  • Can be used for modelling and prediction of Non-linear dynamics

• Usage:
  • Adapt to the moving anatomy in an intelligent and automatic manner.
ADVANCED STRATEGIES

• Conventional solution for respiratory motion - expand PTV
  • Delivering high dose to adjacent structures.
• Optional - Continuous motion tracking and correction
  • Requires advanced correction methods like ART (Adaptive Radiation Therapy) + 4DCT.
4DCT & ADAPTIVE RT

- Typical process:

  Structure
  Segmentation (Contouring)

  Deformable registration
  (Modelling & Prediction)

  IS

  DMLC/Couch
  Adaptation & delivery

  Adaptive Replanning
AUTOMATIC SEGMENTATION

- Delineation of anatomical structures automatically based upon a distance measure or similarity
  - Euclidean Measure – K-Means Clustering
  - FCM - Fuzzy C Means Clustering
  - Texture Analysis
- Drawback – heavy dependence on the model.
 USAGE

- Advantages:
  - Removes interobserver variability
  - Can help in margin reduction
  - Helps in 4DCT to automatically propagate contour with moving anatomy
  - Tissue and tumor modeling for navigation and intervention.
  - Fuzzy approach helps in removal of partial volume effect
- Drawback
  - Heavy dependence on the model.
VIDEO – AUTOMATIC SEGMENTATION
REGISTRATION

- Registration algorithms determine the transformation that map a point from a source image to target image
- Rigid: Affine registration (6 parameters)
  - bony anatomy based
- Non-Rigid Deformation:
  - Elastic, Flow (Navier Stokes)
- Utility: Patient Realignment and Moving anatomy modeling
Prediction filters are needed:
- System latency
- Detection of irregular tumor motion (e.g., unexpected patient cough or movement)
- Prediction from the model
- Ex. ANFIS
Lesion sequence from segmentation

Lesion from ANFIS Prediction
VIDEO – LESION SEQUENCES

Segmented - FCM

Predicted - ANFIS
ADAPTIVE REPLANNING

- Treatment to be best matched with the moving anatomy.
  - Dose changing with moving anatomy to be replanned
  - Time dependent deformable field (ex. Deformable registration) can be used.
DYNAMIC ALIGNMENT OF BEAM/COUCH

- Couch motion
- DLMC (Dynamic Multileaf Collimator) -
A TYPICAL ART SYSTEM

Respiratory monitoring device

Organ motion modelling

Prediction of organ position n samples ahead

Position controller

PSS
ADVANTAGES (4DCT + ART)

- Customize the margin tailored to each patient’s unique tumor characteristics
- Personalized Cancer Therapy
- Holds potential for ”Margin removal”
IGRT COMPANIES & TPS

- Varian – Eclipse TPS
- Elekta – CMS Software
- Siemens – Artis Zeego- intervenssenter
• Errors and Margins in Radiotherapy, Marcel Van Herk Seminars in Radiation Oncology. 2004.
• Management of respiratory motion in radiation oncology report of AAPM task group 76. Keall PJ, et. al., 2006
• Effect of different lung densities on the accuracy of various radiotherapy dose calculation methods: Implications for tumor coverage. LR Aarup et al., Radiotherapy and Oncology. In press 2009
REFERENCES

• Automatic segmentation and recognition of lungs and lesion from CT scans of thorax. Kakar M, Olsen DR. Comp. Med. Imag. Graph;33(1); 2009.


SUMMARY

- What is IGRT?
- Imaging Devices
- Errors and Margins
  - Tumor Delination, Setup Errors, Moving anatomy
  - Correction Strategies
- Case Study - Respiratory motion Compensation
  - Methods for respiratory motion compensation
  - Advanced Strategies (4DCT & ART)