UTSouthwestern
Medical Center
Radiology

TG 291: Principles and Applications of Multienergy CT

Technical implementations of multi-energy CT

Xinhui Duan, PhD, DABR
07/28/2021

2021 AAPM Virtual 63rd Annual Meeting & Exhibition

1

Disclosure

- None

2

Objective

- Understand technical implementations of multi-energy CT
  - How they work
  - Strengths and limitations

3

Content

- 4. Technical implementations of multi-energy CT
  - 4.A. Detector-based methods
    - 4.A.1. Dual-layer detectors
    - 4.A.2. Energy resolving, photon counting CT
  - 4.B. Source-based methods
    - 4.B.1. Consecutive volume or helical acquisitions with different tube potentials per rotation
    - 4.B.2. Acquisitions with rapid tube potential switching
    - 4.B.3. Beam filtration techniques
    - 4.B.4. Dual-source acquisitions

4

Connections to Previous Presentations

- Previous presentations
  - Introduction and Clinical Motivation (Dr. McCollough)
  - Physical Principles of Multi-energy CT (Dr. Flohr)
- Multi-energy CT takes two or more CT images using different photon energies
  - Two key requirements for multi-energy CT imaging
    - Simultaneously (ideally) – avoid motion artifacts
    - Sufficient energy separation – improve image CNR

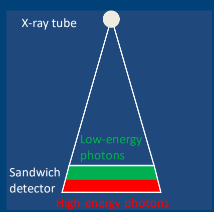
5

UTSouthwestern
Medical Center
Radiology

4.A. Detector-based methods

6

Detector-based methods: 4.A.1. Dual-layer detectors

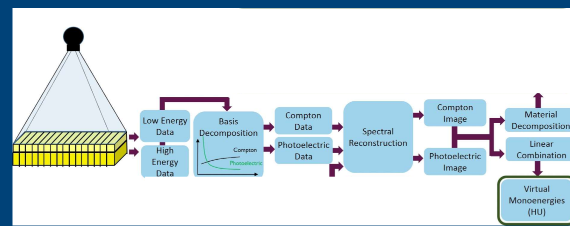


- Description: Two layers of energy-integrating scintillator detectors
- Commercial scanner: iQon (Philips)
  - Top layer: low-density garnet scintillator
  - Bottom layer: GOS (Gd_2O_2S)

UTSouthwestern Medical Center Radiology

7

Dual-Layer Detectors



TG 291 Report, AAPM

UTSouthwestern Medical Center Radiology

8

Dual-Layer Detectors

Strengths

- Absence of special protocols for dual-energy scanning
  - Every 120 and 140 kV scan provides both conventional images and dual-energy images.
  - Salvage studies with suboptimal contrast enhancement and artifacts.
- Spatially and temporally aligned data
  - Projection-space decomposition
  - Anti-correlated noise removal
- No constrains on acquisition
  - Field of view
  - Rotation time
  - Tube current modulation

Limitations

- Only 120 and 140 kV are used for dual-energy imaging
  - 80 and 100 kV scans only generate conventional images
  - Detector layers: materials and thicknesses optimized only for 120 and 140 kV
- Energy separation
  - Smaller than two-kV methods
- Detector cross-talk between layers
  - Scattered photons in different pixels

UTSouthwestern Medical Center Radiology

9

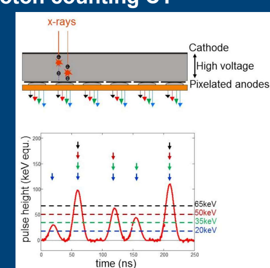
Detector-based methods: 4.A.2. Energy resolving, photon counting CT

- Energy integration

$$S_{int} \approx \int_0^\infty E \cdot N(E)dE$$

- Photon counting

$$S_{count} \approx \int_{E_1}^\infty 1 \cdot N(E)dE$$



TG 291 Report, AAPM

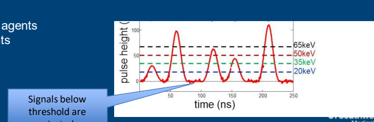
UTSouthwestern Medical Center Radiology

10

Photon-counting Detectors

Strengths

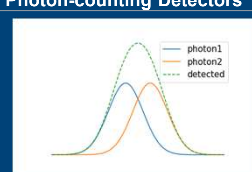
- Similar to dual-layer detectors
- Optimal energy weighting
- Low electronic noise
- K-edge Imaging
  - Adjustable energy bins
  - More than two basis materials: multiple energy bins
  - Applications: multi-contrast agents imaging, new contrast agents
- Optimal energy weighting
  - Example
    - Two photons: 50 and 100 keV
    - Energy integrating: 50/(50+100) = 33%
    - Photon counting: 1/(1+1) = 50%
- Low electronic noise

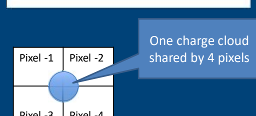


UTSouthwestern Medical Center Radiology

11

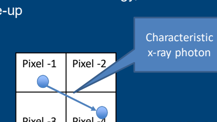
Photon-counting Detectors





Limitations

- Research CT scanners
- Pile-up: incorrect photon energy and count
- Charge sharing and k-escape: reduce spatial resolution, incorrect photon count and energy, increase pile-up



UTSouthwestern Medical Center Radiology

12

UTSouthwestern Medical Center
Radiology

4.B. Source-based methods

13

Source-based methods :
4.B.1. Consecutive volume or helical acquisitions with different tube potentials per rotation

- Axial scan: Two gantry rotations at the same location, each at a different tube potential value.
- Helical scan: two helical scans with the identical trajectory, each at a different tube potential value.

14

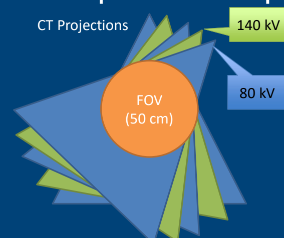
Source-based methods :
Consecutive volume or helical acquisitions with different tube potentials per rotation

Strengths
- Alignment of projection data
  - Projection space decomposition
- Each scan is similar to conventional scans

Limitations
- Motion misregistration and temporal alignment
  - As long as 500 msec to switch tube potential
  - Limits its use: not suitable for cardiac applications or rapid contrast concentration changes

15

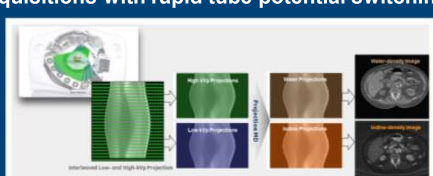
Source-based methods :
4.B.2. Acquisitions with rapid tube potential switching



- Description: Rapidly switching the tube potential back and forth on a view-to-view basis during one scan
  - First commercial Scanner: GE Discovery CT750 HD™, 2008
  - 2000+view per gantry rotation
    - Doubled to avoid aliasing
  - Adjacent views: <0.18°, a fraction of 1 msec time interval.
    - Projection-space decomposition through interpolation

16

Source-based methods :
Acquisitions with rapid tube potential switching



Technical challenges
1. Transition between low and high kVs: special tube and generator
2. Detector temporal response: Gemstone™ scintillator
3. Photon flux: asymmetrical sampling, low energy projection – longer integration (exposure) time.

17

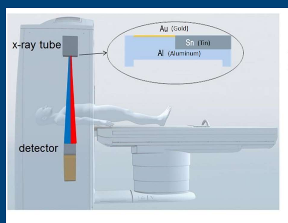
Source-based methods :
Acquisitions with rapid tube potential switching

Strengths
- Alignment of projection data
  - Projection space decomposition
- Full field of view
- Low and high beam flux control through integration time.

Limitations
- Tube current modulation is not available
- Finite switching time between low and high tube potentials – spectral separation

18

Source-based methods :
4.B.3. Beam filtration techniques



- Description: the two halves of x-ray beam are filtered differently in the longitudinal direction
  - Half of detector rows used for the low energy beam and the other half for the high energy beam
  - Commercial scanner: SOMATOM Edge and SOMATOM go (Siemens)
    - "Twinbeam"
    - 120 kV
    - High energy beam: 0.6 mm tin filter
    - Low energy beam: thin gold filter (k-edge 80.7 keV)

UTSouthwestern Medical Center Radiology

19

Source-based methods :
Beam filtration techniques

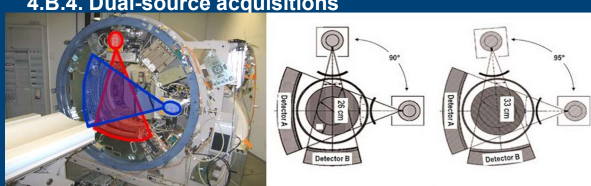
Strengths
- Small modifications of the tube collimator
  - No special tube or generator requirements are necessary.
  - Lower cost
- Full field of view
- Tube current modulation

Limitations
- Spectrum separation smaller than two-kV method
- Powerful generator: strong filtration
- Pitch up to 0.5

UTSouthwestern Medical Center Radiology

20

Source-based methods :
4.B.4. Dual-source acquisitions



- Description: Dual-source CT is a CT system with two measurement systems, i.e., two x-ray tubes and two corresponding detectors, offset within the gantry at an angle of about 90°
  - First commercial scanner: SOMATOM Definition (Siemens), 2006
  - Three generations: FOV of dual-energy imaging 26 cm --> 33 cm --> 35.6 cm

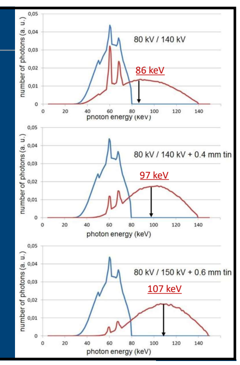
UTSouthwestern Medical Center Radiology

21

Source-based methods :
Dual-source acquisitions

Strengths
- Scan parameters can be individually adjusted for both measurement systems
  - Tube potential and current
- Tube current modulation
- Optimized spectral separation: additional prefiltration into the high-energy beam

80 and 140 kV spectra (after 20 cm water)



UTSouthwestern Medical Center Radiology

22

Source-based methods :
Dual-source acquisitions

Strengths
- Scan parameters can be individually adjusted for both measurement systems
  - Tube potential and current
- Tube current modulation
- Optimized spectral separation: additional prefiltration into the high-energy beam

Limitations
- Smaller central scan field of view for dual-energy imaging
- Image-space decomposition
- Cross-scattered radiation

UTSouthwestern Medical Center Radiology

23

6 Types of Multienergy CTs

- 4.A. Detector-based methods
  - 4.A.1. Dual-layer detectors
  - 4.A.2. Energy resolving, photon counting CT
- 4.B. Source-based methods
  - 4.B.1. Consecutive volume or helical acquisitions with different tube potentials per rotation
  - 4.B.2. Acquisitions with rapid tube potential switching
  - 4.B.3. Beam filtration techniques
  - 4.B.4. Dual-source acquisitions

UTSouthwestern Medical Center Radiology

24

Summary

- Each implementation has unique strengths and limitations
  - Some limitations may be overcome by future technology advancement
- Strengths and limitations discussed in the report may not be directly translated to clinical performance.
  - Literature and user experiences
  - Clinical applications and dosimetry consideration (next presentation by Dr. McCollough)

UTSouthwestern Medical Center Radiology

25

Thank you!

UTSouthwestern Medical Center Radiology

26