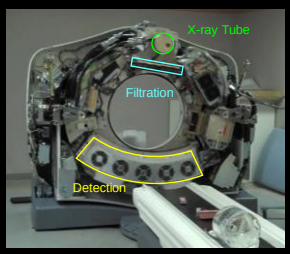
Novel Acquisition Methods in X-ray Computed Tomography

J. Webster Stayman
Department of Biomedical Engineering
web.stayman@jhu.edu

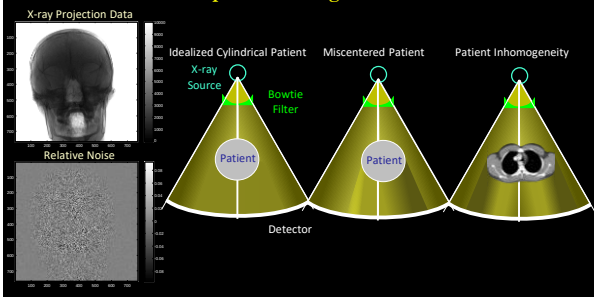
Johns Hopkins University
Schools of Medicine and Engineering

Targets for Novel CT Data Acquisition

- X-ray Source
  - Spatial modulation
  - Spectral modulation
- X-ray Detector
  - Photon-counting
  - Energy discrimination
  - High-resolution systems
- System Geometry
  - Non-circular (non-helical) orbits



Spatial Filtering in CT



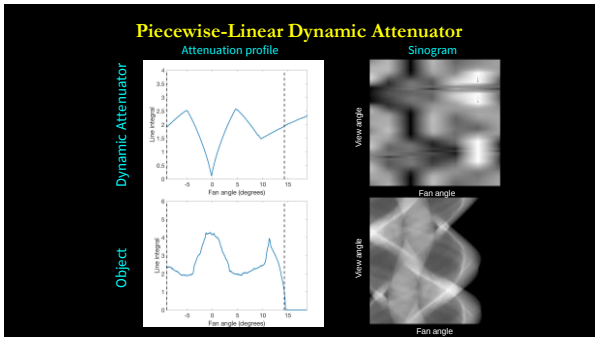
Piecewise-Linear Dynamic Attenuator

3D-printed Stainless Steel Wedge Attenuator

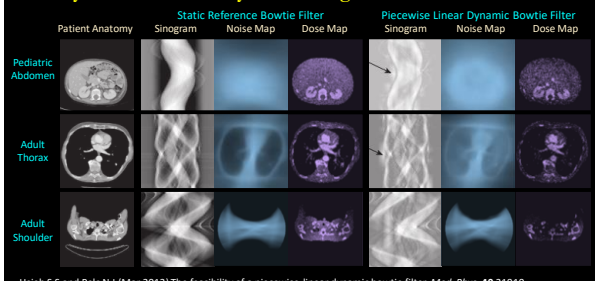
Piecewise-linear Dynamic Attenuator

Shunhavanich, P., Bennett, N. R., Hsieh, S. S., & Pelc, N. J. (June 2019) Implementation of a piecewise-linear dynamic attenuator. *Journal of Medical Imaging*, **6**(2), 023502.

Piecewise-Linear Dynamic Attenuator

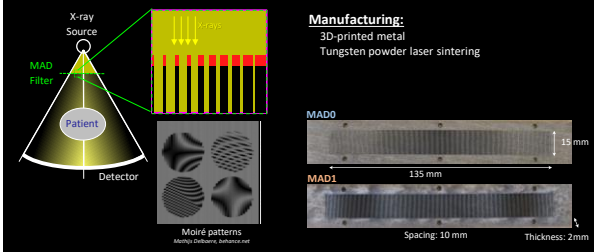


Dynamic Bowtie – Dynamic Range and Dose Reduction



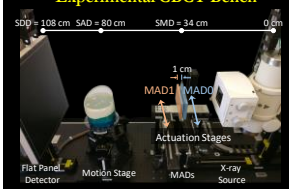
Hsieh S S and Pelc N J (Mar 2013) The feasibility of a piecewise-linear dynamic bowtie filter. *Med. Phys.* **40** 31910

Multiple Aperture Devices (MADs)

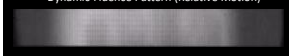


Gang G, Mao A, Wang W, Siewerdsen JH, Mathews A, Kawamoto S, Levinson R, Stayman JW (May 2019) Dynamic fluence field modulation in computed tomography using multiple aperture devices *Physics in Medicine and Biology* **64**(10)

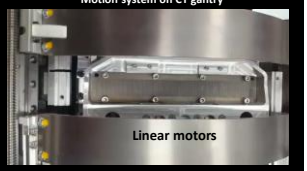
Experimental CBCT Bench



Dynamic Fluence Pattern (Relative Motion)



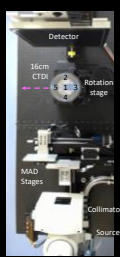
Diagnostic CT Scanner

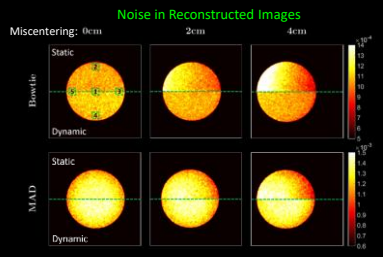


Dynamic Fluence Pattern (Relative Motion)

Gang G, Mao A, Wang W, Siewerdsen JH, Mathews A, Kawamoto S, Levinson R, Stayman JW (May 2019) Dynamic fluence field modulation in computed tomography using multiple aperture devices *Physics in Medicine and Biology* **64**(10)

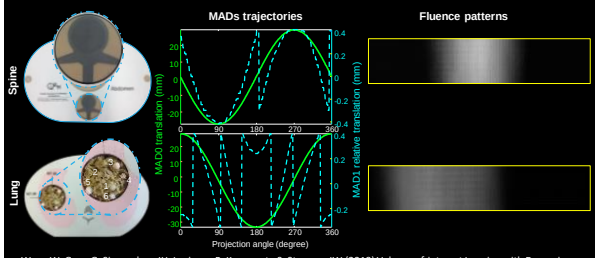
Adapting to Miscentered Patients with Dynamic Bowties





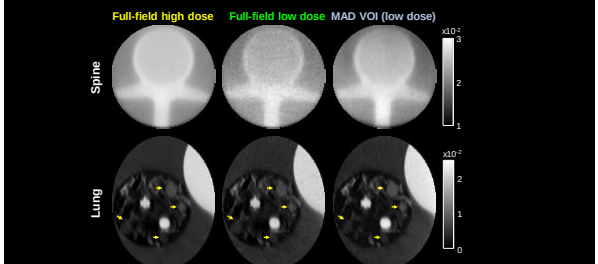
Mao A, Gang G, Shyr W, Levinson R, Siewerdsen JH, Kawamoto S, Stayman JW (Oct 2018) Dynamic fluence field modulation for miscentered patients in computed tomography *J. Medical Imaging*, **5**(4), 043501

MAD-based Volume of Interest Imaging



Wang W, Gang G, Siewerdsen JH, Levinson R, Kawamoto S, Stayman JW (2019) Volume-of-interest Imaging with Dynamic Fluence Modulation Using Multiple Aperture Devices *J. Medical Imaging*, in review.

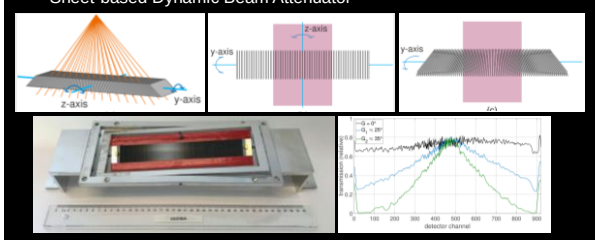
MAD-VOI Reconstructions



Wang W, Gang G, Siewerdsen JH, Levinson R, Kawamoto S, Stayman JW (2019) Volume-of-interest Imaging with Dynamic Fluence Modulation Using Multiple Aperture Devices *J. Medical Imaging*, in review.

Other Dynamic Bowtie Options

Sheet-based Dynamic Beam Attenuator

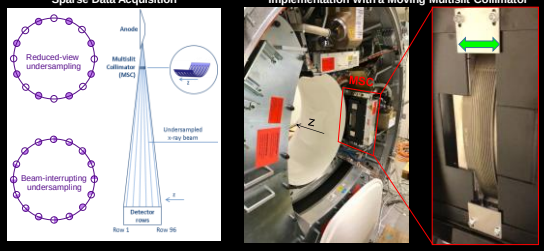


Huck S, Fung G, Parodi K, Stierstorfer K (2019) Sheet-based dynamic beam attenuator – A novel concept for dynamic fluence field modulation in X-ray CT *Medical Physics*, in press.

Sparse Modulation (SparseCT)

Sparse Data Acquisition

Implementation with a Moving Multislit Collimator



Chen B, Kobler E, Allmendinger T, Sodickson A, Sodickson D, Otazo R (July 2019) Effect of Multi-Slit Collimator Motion On SparseCT Image Quality for Low-Dose CT Examinations *AAPM Annual Meeting* (Thursday, 7/18/2019) 7:30 AM - 9:30 AM 221AB

SparseCT Data Reconstruction

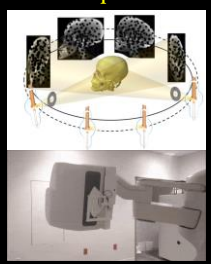
Siemens ADMIRE
120 kVp 210 mAs
100% data

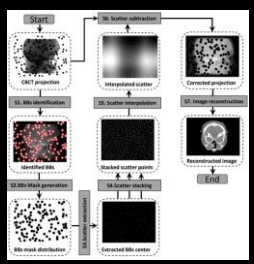
Siemens ADMIRE
120 kVp 21 mAs
100% data

SparseCT
120 kVp 210 mAs
10.4% data

Koesters T, Knoll F, Sodickson A, Sodickson D K and Otazo R (Feb 2017) SparseCT: interrupted-beam acquisition and sparse reconstruction for radiation dose reduction *SPIE Medical Imaging* p 101320Q

Sparse Blockers in Cone-Beam CT

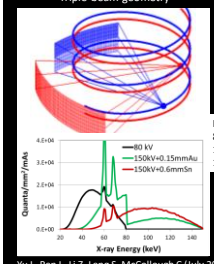




Rezaeian N, Grandinetti J, Xu Y, Li B, Zhu L, Shen C, Jia X (July 2019) Development of a rotational blocker for Cone beam CT dose reduction and scatter correction *AAPM Annual Meeting* (Monday, 7/15/2019)

Spectral Beam Modulation

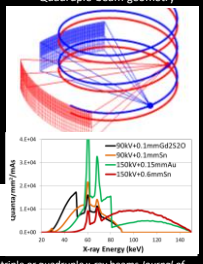
Triple-beam geometry



Mean energy:

80 kV:	52.2 keV
150 kV + Au:	79.7 keV
150 kV + Sn:	98.6 keV

Quadruple-beam geometry

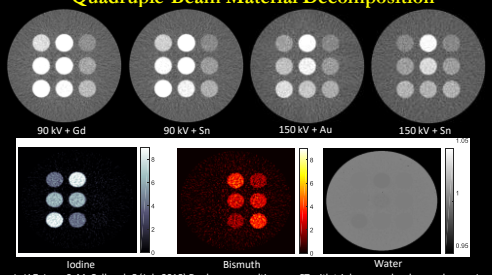


Mean energy:

90 kV + Gd_2S_2O:	56.1 keV
90 kV + Sn:	60.8 keV
150 kV + Au:	79.7 keV
150 kV + Sn:	98.6 keV

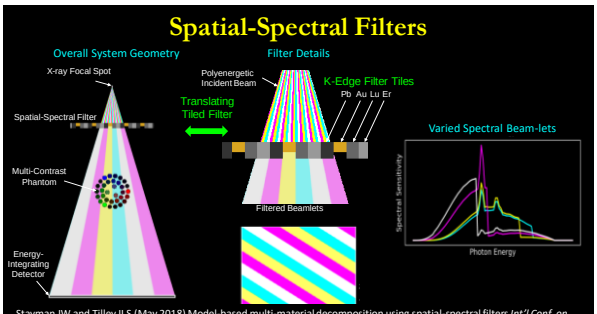
Yu L, Ren L, Li Z, Leng S, McCollough C (July 2018) Dual-source multienergy CT with triple or quadruple x-ray beams *Journal of Medical Imaging* **5**(3)

Quadruple-Beam Material Decomposition



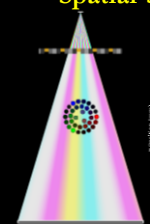
Yu L, Ren L, Li Z, Leng S, McCollough C (July 2018) Dual-source multienergy CT with triple or quadruple x-ray beams *Journal of Medical Imaging* **5**(3)

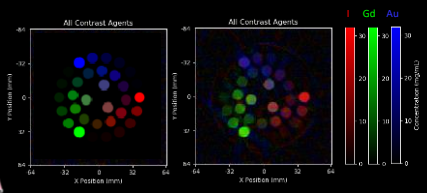
Spatial-Spectral Filters

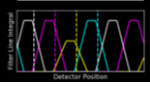


Stayman JW and Tilley II S (May 2018) Model-based multi-material decomposition using spatial-spectral filters *Int'l Conf. on Image Formation in X-Ray Computed Tomography* 102-105.

Spatial-Spectral Simulation and Design



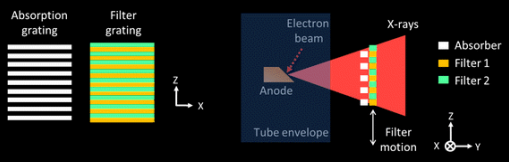




Tivnan M, Wang W, Tilley II S, Stayman JW (July 2019) Designing Spatial-Spectral Filters for Spectral CT *AAPM Annual Meeting*
(Wednesday, 7/17/2019) 7:30 AM - 9:30 AM 221AB

Other Spectral Filtering Approaches

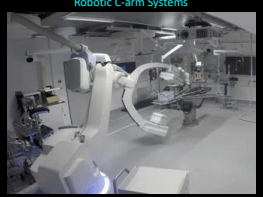
Grating Oriented Line-Wise Filtration:



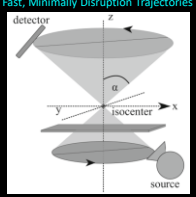
Xi Y, Cong W, Harrison D, Wang G (2017) Grating Oriented Line-Wise Filtration (GOLF) for Dual-Energy X-ray CT. *Sens. Imaging* 18.

Novel Noncircular Geometries

Robotic C-arm Systems



Fast, Minimally Disruption Trajectories

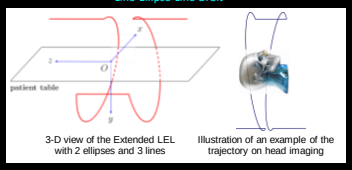


Chung K, Schad L, Zöllner F (May 2018) Tomosynthesis implementation with adaptive online calibration on clinical C-arm systems *Int. J. CARS* **13**, 1481--1495

Novel Noncircular Geometries – Improved Sampling and Image Quality

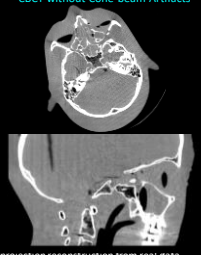
CBCT without Cone-beam Artifacts

Line-Ellipse-Line Orbit



3-D view of the Extended LEL with 2 ellipses and 3 lines

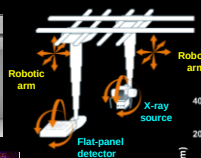
Illustration of an example of the trajectory on head imaging



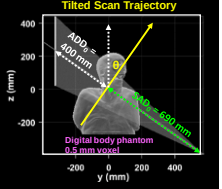
Guo Z, Lauritch G, Maier A, Noo F (June 2019) Theoretically-exact filtered-backprojection reconstruction from real data on the line-ellipse-line trajectory *Int'l Mtg on Fully3D Image Reconstruction*

Novel Noncircular Geometries for Image Quality

Ceiling Mount Robotic Imaging

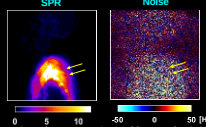


Tilted Scan Trajectory



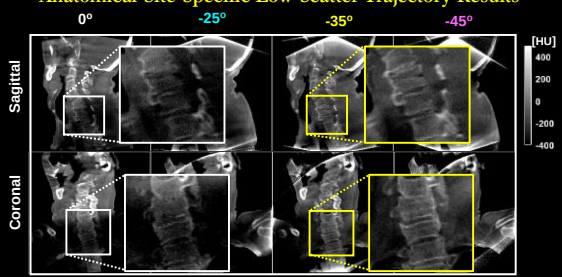
SPR

Noise



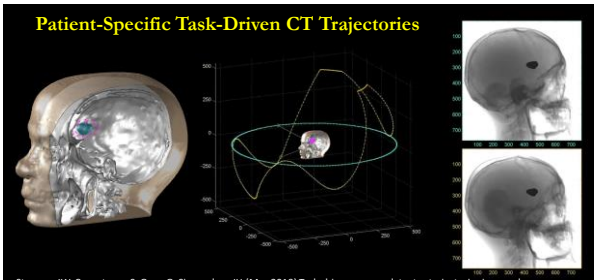
Zhao C, Herbst M, Vogt S, Ritschl L, Kappler S, Siewerdsen JH, Zbijewski W (June 2019) Optimization of cone-beam CT scan orbits for cervical spine imaging *Int'l Mtg. on Fully-3D Image Reconstruction*

Anatomical-Site-Specific Low-Scatter Trajectory Results



Zhao C, Herbst M, Vogt S, Ritschl L, Kappler S, Siewerdsen JH, Zbijewski W (June 2019) Optimization of cone-beam CT scan orbits for cervical spine imaging *Int'l Mtg. on Fully-3D Image Reconstruction*

Patient-Specific Task-Driven CT Trajectories

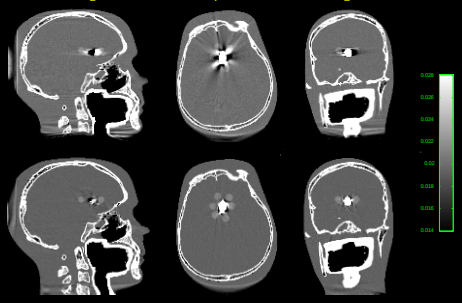


Stayman JW, Capostagno S, Gang G, Siewerdsen JH (May 2019) Task-driven source–detector trajectories in cone-beam computed tomography: I. Theory and methods *Journal of Medical Imaging* **6** (2)
Capostagno S, Stayman JW, Jacobson M, Ehtiati T, Weiss C, Siewerdsen JH (May 2019) Task-driven source–detector trajectories in cone-beam computed tomography: II. Application to neuroradiology Journal of Medical Imaging **6** (2)

Patient-Specific CT Trajectories - Comparison

Circular Scan

Task-Driven Trajectory



Dynamic Beam Modulation

Piecewise-linear	(Shunhavanich *et al* 2019)
	(Hsieh *et al* 2013)
Multiple Apertures	(Gang *et al* 2019)
	(Mao *et al* 2018)
	(Wang *et al* 2019)
Sheet-based	(Huck *et al* 2019)

Sparse Data

Multislit Collimator	(Chen *et al* 2019) (Thursday, 7/18/2019) 7:30 AM - 9:30 AM 221AB
	(Koesters *et al* 2017)
Random Blockers	(Rezaeian *et al* 2019) (Monday, 7/15/2019)

Spectral Modulation

Triple/Quad-Beam	(Yu *et al* 2018)
Spatial-Spectral	(Stayman *et al* 2018)
	(Tivnan *et al* 2019) (Wednesday, 7/17/2019) 7:30 AM - 9:30 AM 221AB
GOLF	(Xi *et al* 2017)

Non-circular Trajectories

Fast Tomo	(Chung *et al* 2018)
Complete Data	(Guo *et al* 2019)
Low Scatter	(Zhao *et al* 2019)
Task-Driven	(Stayman *et al* 2019) (Campostagno *et al* 2019)

Thank You & References

web.stayman@jhu.edu