Cone-Beam CT with Sparse Arrays of Photon Counting Silicon Strip Detectors: Reconstruction, Performance Characterization, and Application to Dual-Energy Imaging

W Zbijewski,1
J Xu,1 S Tilley II,1 G Gang,1 JW Stayman,1
K Taguchi,2 E. Fredenberg,3 M. Lundqvist,3
JA Carrino,2 JH Siewerdsen1,2

1Dept. of Biomedical Engineering, Johns Hopkins University
2Russel H. Morgan Dept. of Radiology, Johns Hopkins University
3Philips Women’s Healthcare, Solna, Sweden

The I-STAR Laboratory
Imaging for Surgery, Therapy, and Radiology
http://www.jhu.edu/istar/

Collaborators
C Bingham, S Ghazarian (JHU Rheumatology)
M Mahesh (JHU Radiology)

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**Si-Strip Photon Counting CBCT**

**Silicon-based PCD**
- Mature technology
- High-quality - fast charge transport
- Low absorption – edge-on

**Pre-Clinical CBCT Bench**
- Si-strip PCD characterization and modeling
- Single- and Dual Energy CBCT reconstruction

**Philips MicroDose**
- Scanning-slot mammography
- Pre-collimator matched to PCD array (not shown)
- Two thresholds (DE)

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**Philips MicroDose**
- Scanning-slot mammography
- Pre-collimator matched to PCD array (not shown)
- Two thresholds (DE)
  - Coincidence detection
  - Adjacent pixels pairs
  - Minimizes charge sharing effects

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Counts #

Threshold

- Coincidence det. OFF
- Coincidence det. ON

Counts #

Threshold

- 70 kVp (+0.2 mm Cu + 2 mm Al)
- 0.105 mAs/frame
- 1 mm Cu (~10 cm water)
Si-Strip Photon Counting CBCT

Detector Modeling
- Cascaded Systems Analysis
- Spatial resolution vs. threshold
- Experimental validation


**Si-Strip Photon Counting CBCT**

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**Characterization**
- Modest energy resolution
- No pulse pileup within the exposure range
- ~120 incident photons/pixel

**Single- and Dual Energy CBCT**
- Discontinuous detector
- ~2.5 mm vertical gaps, ≤5 mm horizontal gaps
- Rotate-translate orbits
- Model-based reconstruction

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**MBR With Sparse Detectors**

**System Model (Likelihood)**
- Projection noise model
- Geometry + gaps
- “Optimal” use of projection samples
- Accommodates complex sampling patterns

**Smoothness Penalty (Regularization)**
- Assumptions about image smoothness
- Dominates in projection gaps

**Application to Si-Strip PCD**
- Poisson PL objective
- Separable Paraboloidal Surrogates
- Quadratic penalty, 100 iterations

Penalized likelihood (PL)
\[
\hat{\mu} = \arg\max_{\mu} L(\mu; y) - \beta \cdot R(\mu)
\]
Scanning Orbits

Range of projection angles where the voxel projects onto Si sensors

1 degree steps
Pixels (4x1): 0.4x0.5 mm²
Voxels: 0.4x0.4x0.5 mm³ voxels

Rotation-Translation Orbits

0.5 mm vertical step
6x180°

0.5 mm vertical step
6x270°

0.5 mm vertical step
6x360°

Spiral 0.5 mm / 360°
Volumetric Imaging

$\beta=5$

$6\times270^\circ$

$6\times360^\circ$

Volumetric Photon Counting CT

Sagittal

Axial

1 degree steps

Pixels (4x1): 0.4x0.5 mm$^2$

Voxels: 0.4x0.4x0.5 mm$^3$ voxels
Single-scan DE imaging
Threshold selection
Maximize separation in $\text{HU}_{\text{LE}} \sim \text{HU}_{\text{HE}}$ space
Relatively weak dependence on threshold

\[
\begin{align*}
\mu_{\text{LE}} & = C_I \mu_{I,\text{LE}} + C_{\text{CaCO}_3} \mu_{\text{CaCO}_3} \\
\mu_{\text{HE}} & = C_I \mu_{I,\text{HE}} + C_{\text{CaCO}_3} \mu_{\text{CaCO}_3}
\end{align*}
\]

Reconstruction-based decomposition
PL with Total Variation penalty

60 kVp (no added filtration)
0.09 mAs/frame
1 mm Cu (~10 cm water)
**Dual-Energy CT with Si-Strip Detector**

Reconstruction-based decomposition
PL with Total Variation penalty
Fraction of voxels classified as >1 mg/mL iodine:
>70% for 2 mg/mL, >95% for 5 mg/mL and 10 mg/mL
<15% for 100 mg/mL CaCO3

**Conclusions**

**Cone-Beam CT with Sparse Detector Arrays**
Rotation-translation orbit + Model Based Reconstruction
Sampling arc ≥ 180° still needed
Future work: spiral scanning trajectory
Regularization vs. non-uniform sampling
Future work: shift-variant regularization

**Photon Counting Dual-Energy CT**
Weak dependence on LE/HE threshold
Relatively high energy spectra compared to detector design
Future work: <60 kVp spectra, pixel gain adjustement
Detection of Iodine: > 90% at 5-10 mg/mL
Future work: artifact correction – equalize pixel thresholds