Inverse Geometry CT

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CT Speed Gains

Multi-slice CT has been the driving technology
Motivation for faster volumetric coverage

- CT angiography
- More reliable cardiac imaging
- Dynamic imaging (perfusion imaging)
- Patient comfort
- Throughput

Cone-beam CT

- Cone-beam artifacts
- Severity increases with increasing axial coverage

Inverse-Geometry CT

- Sources energized one at a time; needs fast detector
- Each source illuminates a fraction of the volume: flux challenge
**Inverse-Geometry CT**

- Source and detector array have ~ same axial extent to avoid cone beam artifacts.

**Potential benefits of IGCT**

- Reduced cone beam artifacts
- More uniform spatial resolution (less variation in apparent focal spot size)
- Less scatter (smaller source solid angle)
- More efficient detectors
- Virtual bowtie

**Scanned source IGCT**

- SBDX scanned anode x-ray source
- ~5x5 cm² photon counting array

**Reconstruction Algorithm**

- PET-type FBP reconstruction

Cone-beam artifacts

Cadaver inner ear

Photon Efficiency

Results: Photon Efficiency

<table>
<thead>
<tr>
<th></th>
<th>2D Parallel Ray</th>
<th>IGCT</th>
</tr>
</thead>
</table>

Theoretical $\sigma=10$ HU
Parallel ray $\sigma=10.5 +/- 1.1$ HU
IGCT $\sigma=9.4 +/- 1.2$ HU

Reconstruction filter cutoff: 7.5 lp/cm
Level: -1000 HU
Window: +/- 50 HU
No noise penalty for using cross plane rays
image noise

\[ \sigma^2 \sim \sum_{\text{views}} \frac{1}{N_i} \]

A few measurements with low intensity can dominate noise

mA modulation

mA modulation can’t change the intensity distribution across fan beam

“Bowtie” filters

“Virtual” bowtie

“bowtie” filter

can’t adapt to the object being scanned or the imaging task

more uniform detected signal
Optimization problem

Solve for intensity of each source in each view to optimize noise for a given dose.

Example: 12 sources, minimize peak variance

Variance maps, same effective dose

Further enhancements

De Man, et al, RSNA 2007
IGCT gantry

detector

source array

Detector array

64 x 256 channels
70 mm (in x)
by 196 mm (in z)

Source array

up to 4 multi-spot modules

2x4 source module

4 electron emitters

x-rays

4 electron emitters

anodes
Electron emitters

32 source array

Gantry integration and balancing

Experimental parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>scan time</td>
<td>1 sec</td>
</tr>
<tr>
<td>sources</td>
<td>8</td>
</tr>
<tr>
<td>pulses per source</td>
<td>125</td>
</tr>
<tr>
<td>kVp</td>
<td>80</td>
</tr>
<tr>
<td>mA</td>
<td>125*</td>
</tr>
<tr>
<td>time per pulse</td>
<td>5.45 μsec</td>
</tr>
</tbody>
</table>

* not at the thermal limit, could be higher
Phantoms

Trail mix
“Defrise”
Bead phantom
Uniform cylinder

Reconstructed coronal images

X-ray flux challenge

**Cause**
- More x-rays removed by our collimators especially as FOV increases
- Stationary anode x-ray sources

**Solutions**
- Higher power
  - more sources, short pulse times, lower duty cycle
- Virtual bowtie
- Higher efficiency detectors
- Statistical reconstruction algorithms

**Target lower dose systems**
Gantry integration and balancing

Stationary source IGCT

only collimator and detectors rotate

Summary

• IGCT potential advantages
  Scalable axial coverage, no cone beam artifacts
  Uniform spatial resolution across FOV
  Better dose efficiency ("virtual bowtie")

• Disadvantages
  No anti-scatter grid (also an advantage)
  X-ray flux challenge

• Much work remains
  Demonstrate virtual bowtie, IQ studies, future configurations

• … but initial results are promising

Thank you!
Stationary source IGCT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source to isocenter distance</td>
<td>60 cm</td>
</tr>
<tr>
<td>Detector to isocenter distance</td>
<td>50 cm</td>
</tr>
<tr>
<td>Field of view (diameter)</td>
<td>44 cm for circular objects</td>
</tr>
<tr>
<td>Detector size</td>
<td>10 cm (transverse) by 15 cm (axial)</td>
</tr>
<tr>
<td>Number of detector cells</td>
<td>103 by 153</td>
</tr>
<tr>
<td>Number of source arrays</td>
<td>3</td>
</tr>
<tr>
<td>Source array length</td>
<td>120 cm</td>
</tr>
<tr>
<td>Crops between source array</td>
<td>6 cm</td>
</tr>
<tr>
<td>Number of views (N) including missing views</td>
<td>1810</td>
</tr>
<tr>
<td>Missing views (in gap)</td>
<td>105</td>
</tr>
<tr>
<td>Earnings per view (M)</td>
<td>23</td>
</tr>
</tbody>
</table>

In-plane sampling is fan-like, no cone beam artifacts. Extra rays reduce noise.

Inverse-Geometry CT

- In-plane sampling is fan-like
- No cone beam artifacts
- Extra rays reduce noise

Cone-beam artifacts

- Indistinguishable objects

Fundamental sampling problem, no correction exists
**“Bowtie” filters**

- cannot be ideal for all objects
- doesn’t work for asymmetric objects
- cannot spare defined sensitive regions

**Recent progress**

- First rotating gantry experiments
- Geometric calibrations
- Algorithm refinements
- Initial images

**Geometric calibration**

need to measure the spatial parameters of sources, axis of rotation, and detector array

**“Bowtie” filters**

with bowtie

- high dose
- non-uniform signal
- relatively uniform noise

- lower dose
- relatively uniform signal
- non-uniform signal