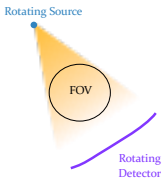
Spatially distributed x-ray sources for inverse geometry CT

Scott Hsieh
AAPM 2017

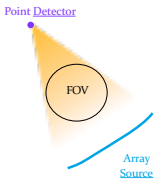
Inverting the scanner

UCLA

Third Generation



Fully Inverted

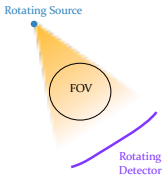


2

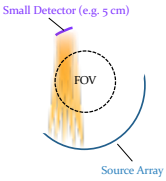
Inverting the scanner

UCLA

Third Generation



Inverse Geometry



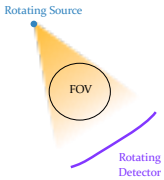
sources pulsed sequentially (requires fast on-off times)

3

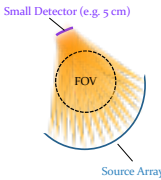
Inverting the scanner

UCLA

Third Generation



Inverse Geometry



sources pulsed sequentially (requires fast on-off times)

4

What is inverse geometry CT?

UCLA

Any architecture which reduces the detector size by using a distributed source array

5

Why inverse geometry?

UCLA

Advantages

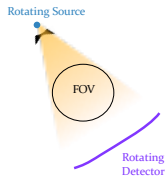
Fine-tune dose utilization ("virtual bowtie")

6

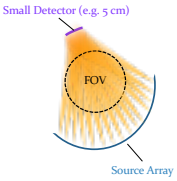
Personalizing Exposure

UCLA

Fixed bowtie, TCM



"virtual bowtie"

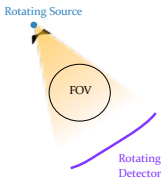


7

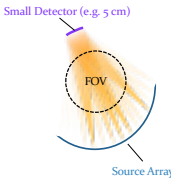
Personalizing Exposure

UCLA

Fixed bowtie, TCM



"virtual bowtie"

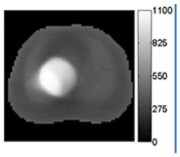


8

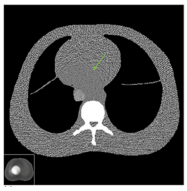
Personalizing Exposure

UCLA

"image quality plan"
SNR distribution



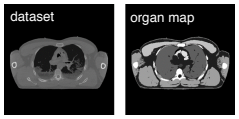
Noise realization



S Bartolac et al, Med Phys 2011

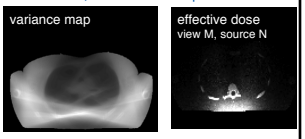
9

input data



UCLA

variance, dose in convex optimization



7x dose reduction at same σ^2_{peak}
(compared to sinusoidal TCM)

modulation technique	eff. dose $[\mu Sv]$ $\lambda_{max} = 18.26 \cdot 10^{-6} cm^{-2}$
sinusoidal	4.61
square root	4.37
CASPAR	
TG	2.16
MS, $S = 5$	0.79
MS, $S = 11$	0.66

Typical dose reductions are ~40%
Hsieh and Pelc, Med Phys 2014

J Sperl et al, IEEE TMI (2010)

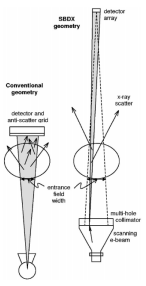
10

Why inverse geometry?

UCLA

Advantages
- Fine-tune dose utilization ("virtual bowtie")
- Reduction of scatter, similar to SBDX
- Elimination of cone beam artifacts

Disadvantages
- Flux requirements
- Complex x-ray source

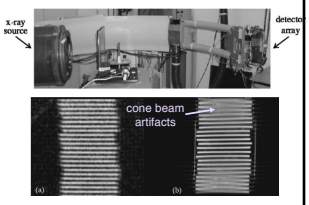


M Speidel et al, Med Phys 2006

Inverse geometry variants

UCLA

Original prototype
- SBDX source, detector
- ~1 MHz framerate
- Demonstrated reconstruction
- Eliminated cone beam artifacts
- Limited FOV (~16 cm)



inverse geometry prototype

GE micro-CT reference

TG Schmidt et al, Med Phys 2004

12

Inverse geometry variants

UCLA

Original prototype
Multi-detector IGCT
- Extends field of view
- Separates detector modules
- Complex collimator
- Tested by sequential acquisition

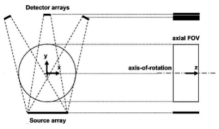


FIG. 2. In-plane and axial views of the multieye IGCT system.

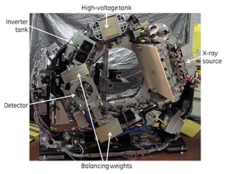
Reconstruction from experimental data (sequential acquisitions), WW = 2000 HU

SR Mazin et al, Med Phys 2007

Inverse geometry variants

UCLA

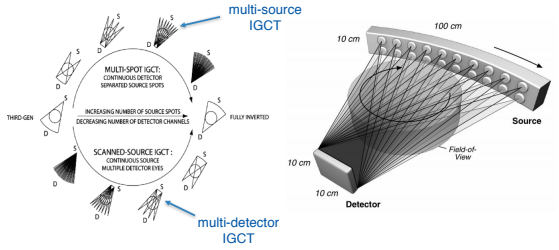
Original prototype
Multi-detector IGCT
Multi-source clinical prototype
- Built at GE GRC
- 32 discrete sources
- 22 cm field of view
- Rotation rate of 1 to 8 s



B De Man et al, Med Phys 2016

A continuum of architectures

UCLA



B De Man et al, Proc. SPIE (2007)

Possible source choices

UCLA

SBDX
- Scanned (dense) source array

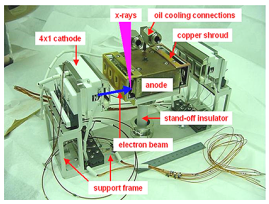
Conventional x-ray source
- Discrete, high-power, large rotating anode
- Size limits # of sources; also needs quick pulses

Dispenser cathode emitter
- Small, modular, stationary anode
- Emits at 1400 K instead of 3000 K, but needs active pumping
- Can achieve 150-300 mA, depending on dwell time

Carbon nanotube or emerging technologies
- Viable candidates

Dispenser cathode emitter

UCLA



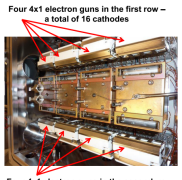
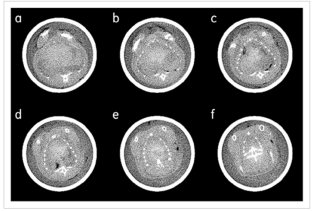


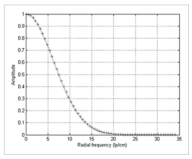
FIGURE 19. 32-spot distributed source demonstrated at GE Global Research, reproduced with permission from Y. B. Neculaes, Y. Zou, P. Zavodszky, L. Inzinna, X. Zhang, K. Conway, K. Frutschy, W. Walters and B. De Man, "Design and characterization of electron beam focusing for x-ray generation in novel medical imaging architecture," Physics of Plasmas, 21, 056702, 2014 [68]. Copyright 2014, AIP Publishing LLC.

Frutschy et al, Proc. SPIE (2010)

Reconstructed images

UCLA



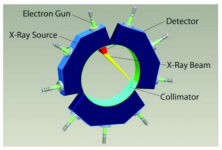


B De Man et al, Med Phys 2016

Inverse geometry variants

UCLA

- Original prototype
- Multi-detector IGCT
- Multi-source clinical prototype
- **Stationary source IGCT**
  - Fast rotation rate (~100 ms)
  - No g-forces on fragile source
  - Fourth-generation architecture
  - Large source, cooling area
  - Never demonstrated



SS Hsieh et al, Med Phys 2013

19

Summary

UCLA

- Inverse geometry CT is a combination of:
  - Small detector
  - Distributed source array
- Pros and cons
  - Pro: dose efficiency, scatter-primary ratio, cone beam artifacts
  - Con: flux needed, especially with larger patients
- Several embodiments
  - Scanned source array
  - Multiple detectors
  - Multiple discrete sources
  - Stationary source array

20