Scanning-Beam Digital X-ray (SBDX) technology for fluoroscopy and angiography

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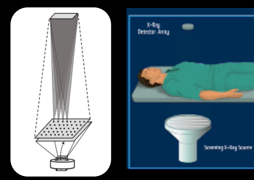
Outline

- Scanning-Beam Digital X-ray (SBDX) is a technology for *real-time fluoroscopy and angiography in the cardiac cath lab*
- Characterized by high speed beam scanning with a 2D array of focal spots
- Learning Objectives
  1. Describe operating principles
  2. Understand potential clinical benefits
  3. Overview of studies and challenges



Triple Ring Technologies, Inc.

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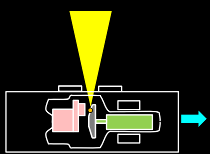
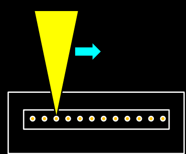
Multisource concepts

- *Traditional x-ray tube:* single focal spot



Mechanical constraints in multi-view imaging modalities

- *Multisource*: Spatially distributed, addressable focal spots



Can enable fast imaging without mechanical motion

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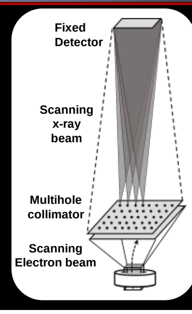
Purpose

- With SBDX, the primary goal is to bring an *advantageous geometry* to fluoroscopy and angiography.
- SBDX geometry is a form of very fast tomosynthesis (15 scan/s).
- Two potential benefits stem from this geometry:

1. **Features that improve dose efficiency**
2. **Depth-resolved image guidance tools**



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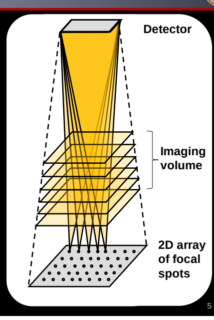
Scanning-Beam Digital X-ray (SBDX)

Triple Ring, Inc.

- "Inverse geometry" fluoroscopy
- 2D array of focal spots and multihole collimator
- Full scan every 1/15 s
- Tomosynthesis recon 32 plane x 15 Hz
- "Composite" recon at 15 frame/s



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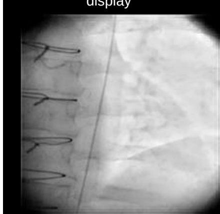
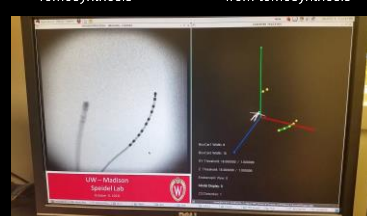
Real-time display modes

- "Composite" display
- Single-plane Tomosynthesis
- 3D device tracking from tomosynthesis





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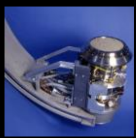
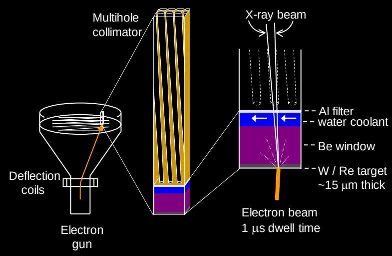
Scanning x-ray tube



Specifications
- 120 kV, 200 mA
- 100 x 100 collimator holes
- 0.68 mm focal spot diam.
- 2.3 mm focal spot pitch
- 1.04 µs dwell time
- 0.24 µs move time



Speidel MA, Wilfley BP, Star-Lack JS, et al., *Med Phys* 33, 2714 (2006).

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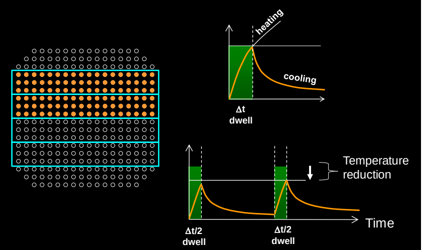
Electron beam scanning technique

- Up to 100 x 100 holes with 2.3 mm pitch
- “Multi-pass blockwise” raster scan
  - Multi-pass lowers peak target temperature
  - Blockwise method limits motion blurring



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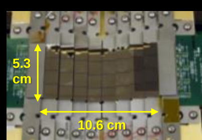
SBDX photon-counting detector

- *Detector must capture an image for each collimator hole illumination*
  - 1.04 µs dwell + 0.24 µs move = 1.28 µs/hole → **781,250 fps**
- Very high speed, very low counts per image

Specifications
- 2 mm thick CdTe
- Readout every 1.28 µs
- 10.6 cm x 5.3 cm area
- 0.33 mm elements
- Single discriminator threshold



(Triple Ring Technologies, Inc.)

Speidel MA, Tomkowiak MT, Raval AN, et al., *Proc. SPIE* 9412:9412W (2015).

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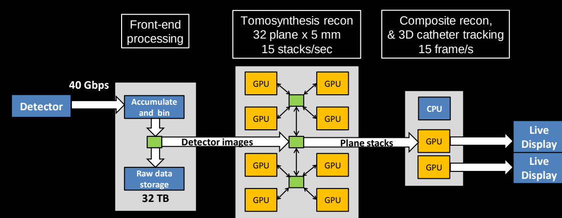
SBDX image reconstructor

- Real-time reconstruction is performed on multiple GPUs



Speidel MA, Tomkowiak MT, Raval AN, et al., *Proc. SPIE* 9412:9412W (2015).

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- Dose Efficiency
- Depth Resolved Image Guidance

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Radiation dose in the cardiac cath lab

- The risk of radiation-induced skin injury and stochastic carcinogenesis are an ongoing concern
- Improvements to system dose efficiency can enable dose reduction without loss of SNR

$$SDNR = C_P\sqrt{\boxed{(1-SF)\mathrm{DQE}\frac{A_{ent}}{A_{obj}}T_{pat}}\,\boxed{\Phi_{ent}}}$$

↑ system efficiency factors

↓ entrance fluence

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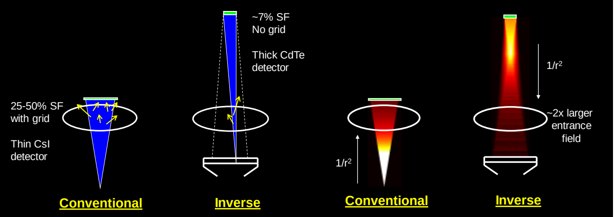
SBDX geometry: advantages

- Narrow-beam scanning with a large air gap reduces detected scatter:
- Inverse geometry "spreads out" the entrance x-rays:



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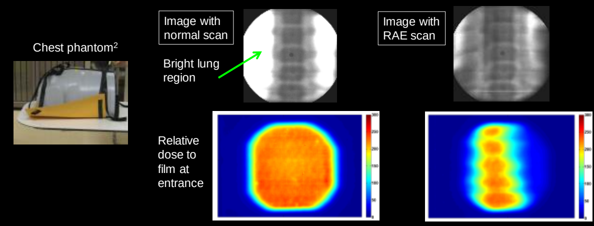
SBDX geometry: advantages

- *Regional adaptive exposure (RAE)*[1]*:* At collimator holes corresponding to high transmission regions, turn off beam current for some scan passes



1. Burion S, Speidel MA, Funk T, *Med Phys* 40:051911 (2013). 2. McCabe BP, PhD thesis (2012)

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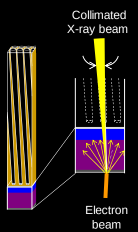
SBDX geometry: challenges

- Upper limit on x-ray output, and SNR, because:

1. Tight collimation limits usable primary x-rays per electron delivered to the anode
2. Electrons are concentrated in a smaller physical focal spot area, for given effective focal spot (no line focus principle)

- On the other hand…

1. Dose efficient system requires less primary x-ray output
2. Short dwell times support high current *density* (550 mA / mm² for 0.68 mm spot @ 120kV)



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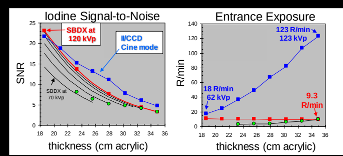
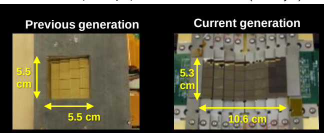
Previous phantom studies

- Iodine SNR and entrance exposure on previous-gen SBDX system, for 18.6-35 cm acrylic phantoms[1]
  - At 120 kV, 107% to 69% of conventional II/CCD SNR in cardiac cine mode
  - While delivering 61% to 8% of the entrance exposure
- This prompted an upgrade which doubled x-ray beam and detector width





1. Speidel MA, et al., *Med Phys* 33, 2728 (2006).

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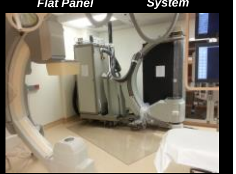
Recent pilot study of coronary angiography

- SBDX was temporarily located in the UW Hospital cardiac cath lab, next to a clinical flat panel system
  - In an IRB-approved study, consented patients requiring diagnostic coronary angiography received standard-of-care angiogram on the clinical system
  - SBDX angiogram acquired with same catheter placement and approximately same contrast injection technique.
- 37 angiogram pairs, 19 subjects, 141-300 lbs.

Clinical Flat Panel *SBDX System*



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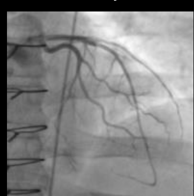
Case: 171 lb., 25 cm chest

Subjective IQ scale

5 - excellent
4 - good
3 - fair
2 - poor
1 - very poor

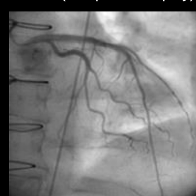
(4 interventional cardiologist readers)

Flat Panel System



25.4 cGy/min at reference point
Average IQ score: 4.8

SBDX (composite display)



10.1 cGy/min (39% conventional)
Average IQ score: 4.5

Unpublished result

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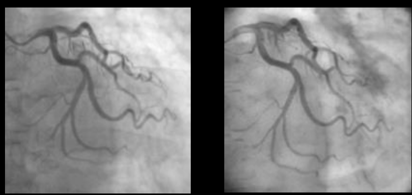
Case: 200 lb., 28 cm chest

Flat Panel System | SBDX System



5 - excellent
4 - good
3 - fair
2 - poor
1 - very poor

40.5 cGy/min
Avg. IQ score: 4.5

11.4 cGy/min (28% conventional)
Avg IQ score: 4.0

Unpublished result

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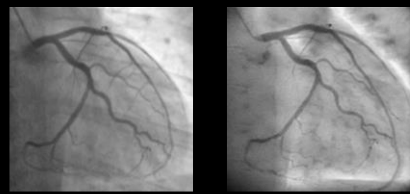
Case: 269 lb., 30 cm chest

Flat Panel System | SBDX System



5 - excellent
4 - good
3 - fair
2 - poor
1 - very poor

40.5 cGy/min
Avg IQ score: 4.5

12.8 cGy/min (32% conventional)
Avg IQ score: 3.8

Unpublished result

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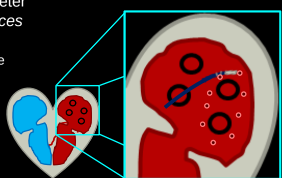
Need for depth resolution in the cath lab

- Clinical problem: Many "non-coronary" procedures require navigation of catheter devices inside relatively *large 3D spaces*
  - 2D projection format gives limited guidance

Example:
Catheter ablation of left atrial fibrillation



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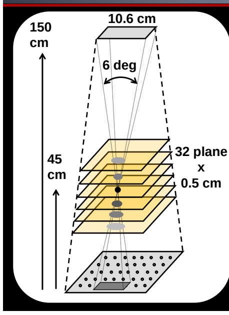
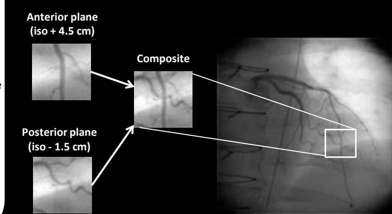
Depth resolved fluoroscopy



- Each "composite" image frame is formed from a stack of 32 planes with 5 mm spacing



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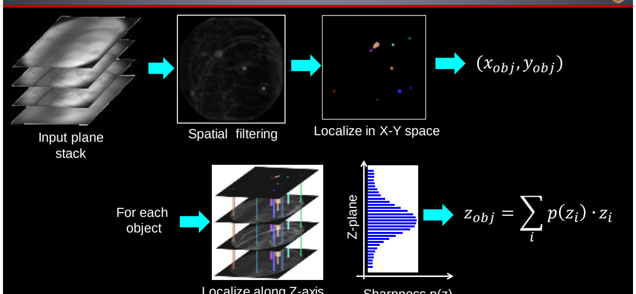
Tomsynthesis-based 3D tracking



Speidel et al., Med Phys 37: 6377 (2010)

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Real-time implementation of 3D catheter tracking

Dunkerley DAP, Speidel MS, RSNA 2016 Annual Meeting (2016)..

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Summary

- Multi-source x-ray tube designs enable fast imaging and provide a way to bring a *new geometry* to a clinical application
- SBDX uses an electronically scanned 2D array of focal spots and high speed detector to perform tomosynthesis at 15 frame/s
- X-ray output limitations and reconstruction optimization are design challenges
- The geometry enables features that can improve dose efficiency and simultaneously provide unique 3D image guidance capabilities.

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