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

Multisource concepts

- Traditional x-ray tube: single focal spot
- Multisource: Spatially distributed, addressable focal spots

Can enable fast imaging without mechanical motion

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

Scanning-Beam Digital X-ray (SBDX)

- “Inverse geometry” fluoroscopy
- 2D array of focal spots and multihole collimator
- Full scan every 1/15 s
- Tomosynthesis recon 3D plane x 15 Hz
- “Composite” recon at 15 frames/s

Real-time display modes

- “Composite” display
- Single-plane tomosynthesis
- 3D device tracking from tomosynthesis
Scanning x-ray tube

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

Multihole collimator

Electron gun

X-ray beam

Al filter

Water coolant

Re window

W / Re target

~15 μm thick

Electron beam 1 μs dwell time

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 \( \rightarrow \) 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

SBDX image reconstructor

- Real-time reconstruction is performed on multiple GPUs

Radiation dose in the cardiac cath lab

- Dose Efficiency
- Depth Resolved Image Guidance

\[
SDNR = C \frac{R_{sys}}{R_{entrance}} \frac{DQE}{\eta_{sys}}
\]

- 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
While delivering 61% to SBDX
At 120 kV, 107% to 69% of
Inverse geometry “spreads out” the entrance x-rays:

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

On the other hand...

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)

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

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

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 angiography 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.

Case: 171 lb., 25 cm chest

Flat Panel System

SBDX (composite display)

Subjective IQ scale

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

(4 interventional cardiologist readers)

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

10.1 cGy/min (30% conventional)
Average IQ score: 4.5

Unpublished result
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

Depth resolved fluoroscopy

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

Tomsynthesis-based 3D tracking

For each object:
- Spatial filtering
- Localize in X-Y space
- Localize along Z-axis
- Sharpness p(z)

Real-time implementation of 3D catheter tracking


Dunkerley DAP, Spade JD, WMA 2016 Annual Meeting (2016).
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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