Stationary Digital Tomosynthesis Using CNT X-Ray Source Array

Otto Zhou, PhD; Jianping Lu, PhD
Yueh Z. Lee, MD/PhD; Cherie Kuzmiak, MD
Enrique Platin, PhD; Andre Mol, DDS/PhD; Lars Gaalaas, DDS

Christy Inscoe, MS; Connor Puett, BS; Allison Hartman, PhD; Jabari Calliste, PhD; Andrew Tucker, PhD; Emily Gidcumb, PhD

Physics, Applied Physical Sciences, Biomedical Engineering, Radiology, Maxillofacial Radiology, University of North Carolina at Chapel Hill

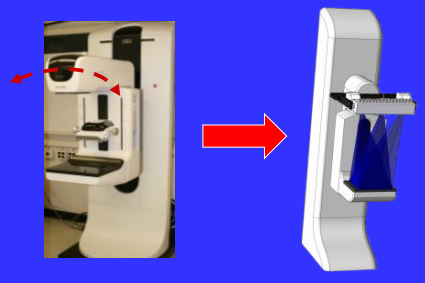
Outline

- Motivation
- Advances in the CNT x-ray source array technology
- Breast tomosynthesis
- Dental tomosynthesis

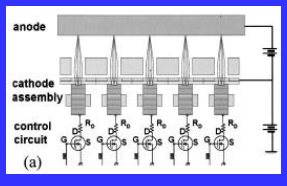
Current Digital Tomosynthesis Scanners

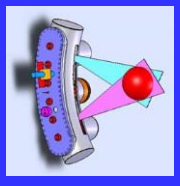
- Mechanically moving an x-ray tube over a finite angular range to collect the projection images for reconstruction
- Focal spot motion blurs the image, reduces detection sensitivity
- Long imaging time, patient motion further degrades image quality

Stationary Tomosynthesis



Enabling Technology: Distributed X-Ray Source Array with Carbon Nanotube (CNT) Field Emitters





Advantages

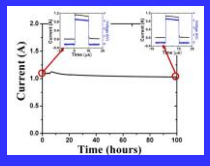
- Field emitted electrons -> Electronically controlled radiation
- Easy physiological gating
- Flexible array configuration

Challenges

- Tube current (mA)
- Energy (kVp)
- Source-to-source consistence
- Reliability

X-Ray Tube Current

- CNT emitters can generate high current needed
- X-ray tube power is limited by anode heat management, no different from a regular x-ray tube
- Current fixed anode design limits the maximum output to what can be achieved with a conventional fixed anode thermionic x-ray tube



1 A emission current from a CNT cathode

Carestream DRX Revolution Nano

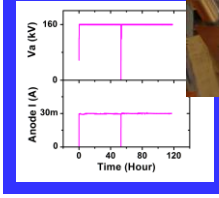
CNT x-ray tube @ 80mA x 110kV(XinRay)
FDA 510 (K) approved

Carestream HEALTH

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

X-Ray Tube Energy

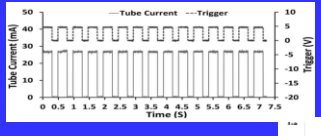
- The unipolar design makes high-voltage more challenging
- Significant improvement in high voltage stability
- 160kVp CNT x-ray source array fabricated

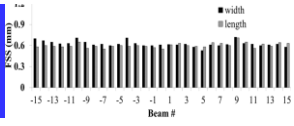


XINRAY systems

Source-to-Source Consistency

- Inconsistency from variations in CNT cathodes, and manufacturing tolerance
- Variation in the x-ray flux readily regulated through an automatic feedback loop in the extraction voltage.
- Variation in the focal-spot sizes are within a reasonable range.





Flexible Array Configuration

- Source array configuration can be tailored for specific system need
- Allow novel geometries for CT and tomosynthesis

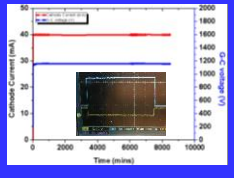
Small dental tomo source, 70kVp, ~3kg total weight

Square, 4x13 sources

1 meter long linear array with 250 focal spots, 160kVp

Lifetime

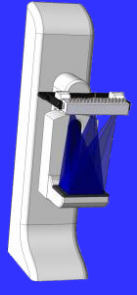
- Depending on the current, current density, vacuum…
- Accelerated lifetime performed for equivalent of 7 yrs (breast tomo) and 5 yrs (dental tomo) tubes



Breast tomo (30kVp x 40mA)
Tested over 7 years equivalent

Dental tomo source (70kVp x 7mA)
Tested over 80K tomo scans
(equivalent of 5 yrs clinical use)

Stationary Breast Tomosynthesis

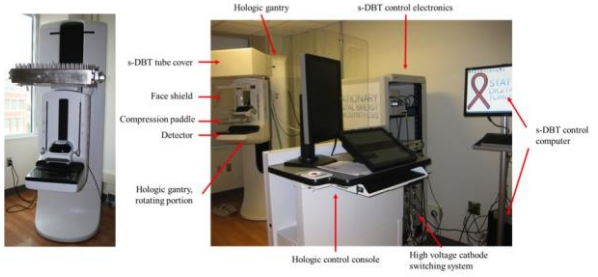


Anticipated clinical benefit

- Higher spatial resolution
- Better sensitivity for micro-calcification
- Shorter scanning time
- Wider angular range
- Less Z –axis artifact
- Less dose (tomo only)

Stationary DBT (s-DBT)

Prototype device in NC Cancer Hospital

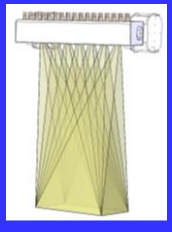


https://clinicaltrials.gov/ct2/show/NCT01773850

Stationary DBT (s-DBT) System

System developed by retrofitting CNT linear source array to Hologic Selenia Dimensions system

- 31 x-ray focal spots
- 30° angular span
- 40 kVp
- Dose matched to conventional DBT tomo
- 2.6 to 4.5 second imaging time
- Images reconstructed on RTT workstation

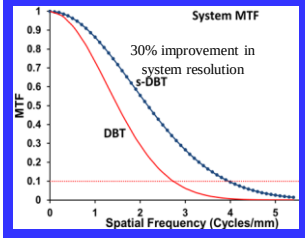


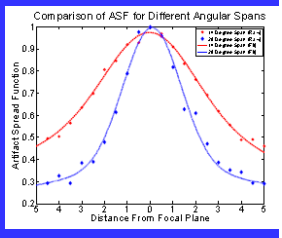
Comparison with commercial systems

	s-DBT	Hologic	GE	Siemens
Scan angle (degrees)	Up to 30 (40*)	15	25	45
Acquisition time (sec)	2.5-4.5 (1.5 – 3.5*)	4	7	25
# of projection images	Up to 31	15	9	25
Scan motion	Stationary	Continuous	Step and shoot	Continuous

* 2nd generation s-DBT tube

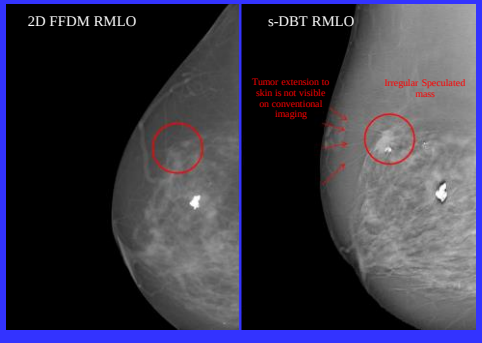
Improved System Resolution

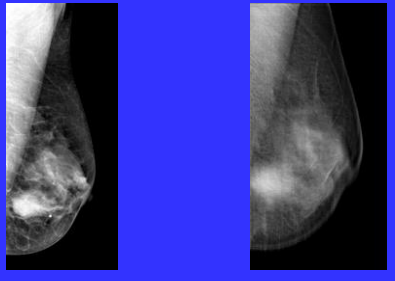




Higher Z-axis resolution

A. Tucker, et al, Med Phys 2013; X. Qian et al Med Phys 2012





LMO view

Dental Imaging: Unmet Clinical Needs

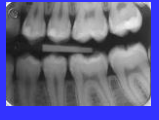
2D Intraoral **Panoramic** **CBCT**



Dental Imaging: Unmet Clinical Needs

2D intraoral x-ray

- The most common dental imaging tool
- 100 million scans per year in U.S.
- 100,000 units/yr sold worldwide



Low sensitivity

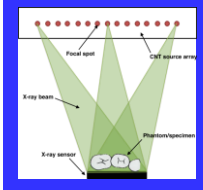
- Caries: most common dental conditions, sensitivity < 50%
- Root fracture: early detection is difficult
- CT does not improve diagnosis accuracy


Prior Works on Dental Tomosynthesis

- Webber, et al. invented Tuned Aperture Computed Tomography (TACT)
  - Fiducial marker
  - Manual translation of a conventional dental x-ray tube
  - Significant improvement in the diagnostic accuracy for fractures, periodontal diseases
  - Results on caries are inconclusive
- TACT is not used clinically
  - Long imaging time
  - Require fiducial marker

Intraoral Tomosynthesis with CNT X-Ray

- Linear CNT x-ray source array @ 70kVp x 7mA (clinical standard setting)
- Standard intraoral sensor, 35.52mm x 26.64mm (1920 x 1440 pixels, 18.5um x 18.5um each).
- Total dose from a tomo scan is the same as one 2D x-ray (PSP detector)
- Iterative reconstruction

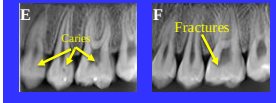


Phantom Imaging: 3D vs 2D

State of art 2D x-ray

3D intraoral

3 metal fillings

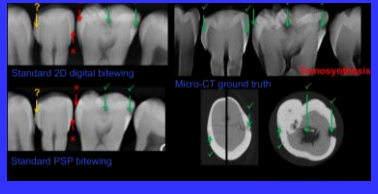


Increased visualization of dental anatomy, caries, and tooth fractures compared to standard 2D image

J. Shan et al. *Dentomaxillofacial Radiology. 2015*

Reader Study

Objective: Compare 3D intraoral with clinical 2D x-ray for caries detection
Specimen: Extracted human teeth
Ground truth: Micro-CT
Observers: 8 experienced dentists from UNC Dentistry
Conclusion: 36% increase in sensitivity for caries detection



AAOMR (American Academy of Oral and Maxillofacial Radiology) 2016

Ongoing Patient Imaging Study

Objective: Conventional Bite Wing Radiography vs 3D Intraoral
100 patients from UNC Dental Clinic.

(https://clinicaltrials.gov/ct2/show/NCT02873585)

Disclosures

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