NERS/BIOE 481

Lecture 11
Computed Tomography (CT)

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A) X-ray Computed Tomography ...(L11)
B) CT Reconstruction Methods ...(L11/L12)
A) X-ray Computed Tomography

1. Basic Concepts (2 slides)
2. Historical Developments
3. X-ray Source
4. Detectors
5. Multi-slice scanners
6. Recent Advances
7. Cone beam systems
8. Tomosynthesis systems
IV.B.2 - the Radon transform

• The argument of the exponential factor describing the attenuation through an object path is known as the Radon transform.

• It’s form is that of a generalized pathlength integral of a density function.

• The inverse solution to the Radon transform, i.e. $\mu(x,y)$ as a function of $P(r, \theta)$, is used in computed tomography.

\[
P(r, \theta) = -\ln \left( \frac{\varphi}{\varphi_o} \right) = \int_0^T \mu(t) dt
\]

In the Radon transform equation above, the attenuation shown as a function of the projection path variable, $\mu(t)$, is more formally written as $\mu(r, \theta)$ or $\mu(x,y)$.

The line integral of $\mu(t)$, $P(r, \theta)$, is referred to as a 'Projection Value'. The set of all values obtained in one exposure is called a 'Projection View.'
VII.A.1 - The inverse Radon transform

• CT image reconstruction seeks a solution for the material properties of an object, $\mu(x,y)$, based on projections measurements, $P(r, \theta)$, taken at many positions and orientations as indicated by $r$ and $\theta$.

• In 1917, Radon proved that a solution exists if $P(r, \theta)$ is known for all values of $r$ and $\theta$.

• Practical numeric methods to solve this problem were not developed until 50 years later.
A) X-ray Computed Tomography

1. Basic Concepts
2. Historical Developments (16 slides)
3. X-ray Source
4. Detectors
5. Multi-slice scanners
6. Recent Advances
7. Cone beam systems
8. Tomosynthesis systems
Early CT History

- **1917**
  Radon’s theory of image reconstruction from projections

- **1956**
  Bracewell constructed solar map from projection data

- **1961, 1963**
  Oldendorf, Cormack developed Laboratory CT devices

- **1968**
  Kuhl & Edwards developed nuclear imaging tomography device.

- **1972**
  Godfrey Hounsfield and the Central Research Laboratory of EMI, Ltd complete the development of a medical CT device for scanning the human head.

EMI Laboratory Device
A pencil beam of radiation is scanned linearly across the subject to acquire a set of parallel projections.
1st Generation Translate - Rotate Geometry

- The gantry is rotated slightly and the linear scan repeated.
1st Generation Translate - Rotate Geometry

- A large number of translate scans is performed with small angle changes.
- Completion of a scan for a single slice required about 5 minutes.
The last translation scan is obtained at 180 degrees of rotation relative to the first translation.

The 1st generation geometry was used in early EMI head and body scanners and devices built by Neuroscan and Pfizer.
1973

First commercially available clinical CT head scanner on market (EMI)

- One of the first EMI head CT scanners in the US was installed at Henry Ford Hospital (Detroit, MI) in 1973.
- The CT image shown to the left was obtained at the Cleveland Clinic in 1974. A large meningioma has been enhanced by iodinated contrast material.
2nd Generation
Translate - Rotate

- A set of radiation beams arrange in a fan geometry is scanned linearly across the subject.
- This allows multiple sets of parallel beam projections to be acquired at the same time.
2\textsuperscript{nd} Generation Translate - Rotate

- A relatively large rotation step is made and the translation scan repeated.
- This approach was used in 1975 by Technicare and then by EMI for head and body scanners.
- Scan times were reduced to 2 minutes and eventually 20 secs.
In 1976, devices were introduced for which the number of detectors and the width of the fan allowed the scan circle to be fully measured with one x-ray pulse.

Simple rotation of the x-ray tube and detector assembly provided all measurements needed for image reconstruction.
VII.A.2 - 1976 Fan Beam Method (3\textsuperscript{rd} Generation)

- Improved detectors and scanning mechanisms led to rotating fan beam devices in 1976 with 5 sec scan times.
- In the next two years, systems were sold by GE, Varian, Searle, Technicare, and Siemens. This design is still employed in modern medical CT scanners.
- Since each detector element tracks a circle, careful calibration is needed to avoid ring artifacts.
• In 1977, devices with a fixed ring of detectors and a rotating x-ray tube were introduced by AS&E (Pfizer) and Picker.

• These devices were not susceptible to detector fluctuation artifacts (ring) and were adopted by other companies.

• A single detector acquires a fan beam of projections as the x-ray tube rotates past the scan circle.
VII.A.2 - 1977 4th Generation Systems

- The signals acquired by all detectors form a set of rotating fan beams similar to than acquired with 3rd generation systems.
- Because the approach requires more detectors, the 4th generation approach has not be used to date for multi-slice scanners.
- Detection Efficiency & Dose:
  If x-rays are detected efficiently, the image noise associated with a specific pixel size and slice thickness is limited by the amount of radiation energy deposited in the patient.

- Image Quality:
  The resolution and noise of medical CT images has improved only modestly since 1985.

- Speed:
  However, the acquisition speed has improved dramatically.
Continuous scanning was introduced in 1990 using slip-ring technology for electronic interface to the detector and x-ray tube and continuous motion of the patient table.

The 3rd generation geometry was adopted for helical/spiral devices and eventually extended to the modern multislice scanner.
These systems were labeled as either:

- *spiral* (Siemens)
- *helical* (GE)

because of the motion of the tube-detector relative to the patient.

In 1990, the Siemens Somatom Plus-S achieved 32 second continuous spiral scan with constant tabletop feed. Subsecond (.75 s) rotation speed achieved in 1994 with the Somatom Plus 4.
VII.A.2 - 2000 - Increased Volumes

The amount of image data acquired increased 6X from 1990 to 2000 due to:

- Helical/Spiral scan geometry
- Improved reconstruction time
- Improved X-ray tube heat capacity

1990:
- 25 cm scan length
- 10.0 mm thick scans
- 25 slices

2000:
- 25 cm scan length
- 1.25 mm thick scans
- 150 slices
A) X-ray Computed Tomography

1. Basic Concepts
2. Historical Developments
3. X-ray Source (9 slides)
4. Detectors
5. Multi-slice scanners
6. Recent Advances
7. Cone beam systems
8. Tomosynthesis systems
VII.A.3 - Tube Capacity and scan time

- Modern CT tubes exceed 7-8 MHU with cooling rates of 1.4 MHU/min.
- Typical technique is 120-140 kVp, 100-400 mA-s (.1 to .5 MHU/sec)
- Tube heat capacity may limit the scan time in one run. A time delay is then required before the next scan is started.

- Multi-slice scanners complete a full scan more quickly and thus produce less heat loading than single slice scanners.

1 Heat Unit (HU) = 1 Joule
\[ V \times A = \text{Watts} = \text{HU/sec} \]
Modern scanners with continuous rotation use high power tubes with fast rotation time.

The high heat load of CT xray sources requires oil coolant circulation and heat exchanger units.

GE Performix HD Tube
Up to 680 mA on the small focal spot
VII.A.3 - Cooled Anode x-ray tube.

One manufacturer (Siemens) uses an x-ray tube where the entire tube body rotates, rather than just the anode, as is the case with conventional designs. This change allows all the bearings to be located outside the evacuated tube, and enables the anode to be cooled more efficiently.

- The Straton has a low inherent heat capacity of 0.8 MHU, but an extremely fast cooling rate of 5 MHU/min (83 kHU/sec).
- This permits continuous scanning with no time limit at 120 kVp and 700 mA.
VII.A.3 - X-ray Beam Collimation

• X-rays are collimated to a fan beam using collimating shutters placed before and after the patient.

• The post patient collimator provides a more well defined beam profile in the Z direction but removes radiation signals that have exposed the patient.
VII.A.3 - Beam Shaping (Bow-tie) Filter

- Beam shaping (Bow-tie) filters provide a more constant signal to all detector elements.
- X-ray spectral shape is kept similar which reduces artifacts.
- Radiation dose at the patient surface is reduced.
VII.A.3 - Dynamic Flux Control

- mA is reduced when the x-ray attenuation is low.
- mA is increased when the attenuation is high.
- 1985: Developed using sinusoidal variation in mA.

Toth, Technicare, US5400378.

Advanced systems now automatically monitor transmission versus rotation and dynamically adjust mA.
VII.A.3 - Dynamic Flux Control

- Underpenetration causes excessive noise and anisotropic noise texture.
- Dynamic flux control equalizes the noise and eliminates noise streak artifacts.
A) **X-ray Computed Tomography**

1. Basic Concepts
2. Historical Developments
3. X-ray Source
4. **Detectors (7 slides)**
5. Multi-slice scanners
6. Recent Advances
7. Cone beam system
8. Tomosynthesis systems
The ionization of high-pressure xenon gas molecules produces ions (+) and electrons (-) that migrate to oppositely charged collection plates. The current produced is converted to a voltage that is proportional to the rate at which radiation energy is absorbed.

These detectors were used for early fan beam systems such as the GE 7800, 8800, and 9800 systems made from 1975 to 1985.
VII.A.4 – Solid Scintillation Detectors

- X-rays absorbed in the scintillation material produce light in proportion to the amount of energy deposited.
- This light is detected by a photodiode and converted to a voltage level by a preamplifier.

For single slice scanners, each detector element is long relative to the magnified Z width of the fan beam. X-rays from the entire beam width are integrated for any slice width.
VII.A.4 - Scintillator-photodiode detectors

- Most systems made later than ~1988 have used scintillator photodiode detectors.

- Early systems used:
  - Bismuth Germanate (BGO),
  - Gadolinium OxySulfide ($\text{Gd}_2\text{O}_2\text{W}$),
  - Cadmium Tungstate ($\text{CdWO}_4$).

- Recent designs have used ceramic scintillators made from yttrium/lutetium oxides and europium oxides with rare earth impurities that produce very fast response with little afterglow. (GE HiLight, Siemens UFC).
VII.A.4 - CT detector after-glow

- Primary decay time constant, $\alpha_1$, is for fast $e^{-t/\alpha_1}$ decay.
- Typical scan times are 1000 times the primary decay time.

Two early GE HiLight detectors

$\alpha_1 \sim 1 \text{ msec}$

Hsieh, IEEE TMS, 2000
VII.A.4 - Multi-slice Detectors

- Detectors with multiple elements in the Z direction were introduced in 1998.

- Helical scans done with multiple element detectors provide thinner slices for the same x-ray beam width.

- Alternatively, faster table motion can be used with a thicker x-ray beam to obtain the same slice width as for a single detector scan.
The current generation of CT scanners uses large area detectors with modular design.

Broad fan beams increase scattered radiation.
Anti-scatter grids can improve contrast.

Media link for Philips CT detector

GE CT750 HD Detector Module (garnet)
Current detector modules have reduced noise resulting in improved performance for low mA techniques.

Data obtained using a 40cm diameter water phantom.
A) **X-ray Computed Tomography**

1. Basic Concepts
2. Historical Developments
3. X-ray Source
4. Detectors
5. **Multi-slice scanners (9 slides)**
6. Recent Advances
7. Cone beam systems
8. Tomosynthesis systems
VII.A.5 - Helical CT Pitch

- In modern scanners, the x-ray tube and detector rotate continuously with slip ring bearings as the table moves with velocity, $v_t$.
- The width of the x-ray beam at the rotation center, $B_w$, is illustrated in Fig-B for a 360 degree rotation.
- The subject moved twice the beam width during this rotation.
- The scan pitch is defined as (table travel / beam width):

$$P = \frac{(v_t \times t_r)}{B_w}$$

- $P$ = Pitch
- $v_t$ = table velocity
- $t_r$ = rotation time
- $B_w$ = beam width
VII.A.5 - Helical CT Pitch

- Measurements should be made from all directions for each point in the region of reconstruction.
- A pitch of 2 leaves portions of the subject incompletely sampled.
- A pitch of 1.0 provides some redundant sampling.
- Pitch values of about 1.1 - 1.3 are common.

\[
P = \frac{v_t \times t_r}{B_w}
\]

- \(P\) = Pitch
- \(v_t\) = table velocity
- \(t_r\) = rotation time
- \(B_w\) = beam width
VII.A.5 - Helical CT beam width

- The detector elements for the projections through a point in the object depend on the detector rotation because of the table movement.

- The width of a reconstructed slice is determined by the reconstruction region considered rather than by collimation.
VII.A.5 - Helical CT - slice width and position

• The CT image has a slice width and position determined by the reconstruction.
• Slice intervals that overlap the slice width provide improved object sampling.
• Thin overlapped slices are used for coronal and sagittal views and for 3D surface renderings.

Note: The slice positions in this figure have been displaced vertically to illustrate the overlap of the slice widths.
Table:

<table>
<thead>
<tr>
<th>Year</th>
<th>Slice</th>
<th>Thickness</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>4</td>
<td>20 mm</td>
<td>0.70-0.80 sec</td>
</tr>
<tr>
<td>2002</td>
<td>16</td>
<td>20 mm</td>
<td>0.40-0.50 sec</td>
</tr>
<tr>
<td>2005</td>
<td>64</td>
<td>40 mm</td>
<td>0.35-0.40 sec</td>
</tr>
<tr>
<td>2008</td>
<td>256+</td>
<td>80+ mm</td>
<td>&lt; 0.30 sec</td>
</tr>
</tbody>
</table>
### 64 slice scanners, c. 2006

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Data Channels (# x mm)</th>
<th>Detector Z Length (mm)</th>
<th>Rotation Speed (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE LightSpeed VCT</td>
<td>64 x 0.625</td>
<td>40</td>
<td>0.35</td>
</tr>
<tr>
<td>Philips Brilliance 64</td>
<td>64 x 0.625</td>
<td>40</td>
<td>0.40</td>
</tr>
<tr>
<td>Siemens Sensation 64</td>
<td>64 x 0.6* 24 x 1.2</td>
<td>28.8</td>
<td>0.37 (.33 opt.)</td>
</tr>
<tr>
<td>Toshiba Aquilion 64</td>
<td>64 x 0.5</td>
<td>32</td>
<td>0.40</td>
</tr>
</tbody>
</table>

* 64 x 0.6 mm data channels achieved using 32 x 0.6 mm detectors and z-axis flying focal spot
**128 - 320 slice CT scanners, c. 2010**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Data Channels</th>
<th>Z Length (mm)</th>
<th>Rotation Speed (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE CT750 HD</td>
<td>128</td>
<td>40</td>
<td>0.35</td>
</tr>
<tr>
<td>Philips Brilliance iCT</td>
<td>128</td>
<td>80</td>
<td>0.33</td>
</tr>
<tr>
<td>Siemens Definition AS*</td>
<td>128</td>
<td>38</td>
<td>0.30</td>
</tr>
<tr>
<td>Toshiba Aquilion ONE</td>
<td>320</td>
<td>160</td>
<td>0.35</td>
</tr>
</tbody>
</table>

* 128 data channels achieved using 64 detectors and z-axis flying focal spot
VII.A.5 - 128 slice CT scanner

GE CT750 HD

Media link on rotation
VII.A.5 - Multi-Slice Applications

Multi-slice technology has led to:

- Increased use of CT angiography.
- Thin slice lung scans with single breath hold.
- Whole body scans and increased utilization for trauma evaluation.
- Increased use of 3D image analysis.
- Cardiac dynamic imaging.
A) X-ray Computed Tomography

1. Basic Concepts
2. Historical Developments
3. X-ray Source
4. Detectors
5. Multi-slice scanners
6. Recent Advances (12 slides)
7. Cone beam systems
8. Tomosynthesis systems
VII.A.6 – Recent Designs

2014 – GE Revolution CT

Gemstone Clarity detector (garnet)

NEW INTEGRATED MODULE

256 data channels
- 0.625 mm row thickness
- 160 mm Z coverage

Improved center mount design
- 0.28 sec rotation time
- 0.20 sec gantry rating

Note: @ rotation center

Media link on detector

4/2014 FDA approval
VII.A.6 - Recent Designs

Siemens Dual Source CT scanners

**2012 - Somatom Definition Flash**

Detector: 2 x Stellar detector
Number of slices: 256 (2 x 128)
Rotation time: 0.28 s
Temporal resolution: 75 ms
Generator power: 200 kW (2 x 100 kW)
kV steps: 70, 80, 100, 120, 140 kV
Isotropic resolution: 0.33 mm
Max. scan speed: 458 mm/s with Flash Spiral

**2014 - Somatom Force**

Detector: 2 x Stellar detector with 3D Anti-Scatter collimator
Channels: 384 (2 x 192)
Rotation time: up to 0.25 s
Temporal resolution: 66 ms
Generator power: 240 kW (2 x 120 kW)
kV settings: 70-150 kV, in steps of 10
Spatial resolution: 0.24 mm
Max. scan speed: 737 mm/s with Turbo Flash
VII.A.6 - Recent Designs, Dual Energy

Dual Energy CT

Dual source CT systems that set kV and filtration differently on each source provide high quality material specific images.

Pulmonary perfusion is shown in red from DE identification of iodine contrast material.

Two X-ray sources set to different kV levels simultaneously acquire two data sets at different attenuation levels.
VII.A.6 - Recent Designs, Dual Energy

GE CT750 HD

High Speed kV switching

• 0.5 second rotation
• 0.5 ms kV switching
• Dual energy prereconstruction algorithm
• Computes:
  • Effective Z
  • Density
  • 'mono E' images

Goodsitt M et. al., Accuracies of the synthesized monochromatic CT numbers and effective atomic numbers obtained with a rapid kVp switching dual energy CT scanner, Medical Physics 38 (4), 2011.
Coronary artery Dual Energy tissue identification
VII.A.6 - Recent Designs, Dual Energy

Philips IQon Spectral CT

Multi Layer Detector

- yttrium-based garnet scintillator for detection of lower energies
- gadolinium oxysulphide (GOS) scintillator for detection of higher energies
- Thin front-illuminated photodiode (FIP), which is placed vertically.

  The photodiode lies beneath the anti-scatter grid as to not degrade the overall geometric efficiency of the detector

- Integrated application-specific integrated circuit (ASIC) for analog-to-digital conversion.

  - While not ideal for DE material imaging, SE & DE is obtained at the same time.
  - The detector offers potential for CNR improvement from energy weighting.

11/2014 FDA approval
VII.A.6 - Recent Designs, Inverse Geometry

Prototype system
- Stanford Univ.
- GE Global Research

Table 1. System parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source to isocenter distance</td>
<td>450 mm</td>
</tr>
<tr>
<td>Detector to isocenter distance</td>
<td>385 mm</td>
</tr>
<tr>
<td>Source spacing in x and z</td>
<td>25 mm and 100 mm</td>
</tr>
<tr>
<td>Detector dimension in x and z</td>
<td>70 mm × 192 mm</td>
</tr>
<tr>
<td>Detector cell size in x and z</td>
<td>1.1 mm × 1.0 mm</td>
</tr>
<tr>
<td>FOV(axial × transverse)</td>
<td>75 mm × 160 mm</td>
</tr>
<tr>
<td>Source voltage</td>
<td>80 kVp</td>
</tr>
<tr>
<td>Source current</td>
<td>125 mA</td>
</tr>
<tr>
<td>Exposure time per source location per view</td>
<td>5.4 μs</td>
</tr>
<tr>
<td>Number of views per source</td>
<td>125/360°</td>
</tr>
<tr>
<td>Rotation time per revolution</td>
<td>1 s</td>
</tr>
</tbody>
</table>
VII.A.6 - Recent Designs, Inverse Geometry

Prototype system
- Stanford Univ.
- GE Global Research
(a) A research PCD-based CT system, built based on a second-generation dual-source CT system, consists of an EID and a PCD.

(b) Detector configuration of the UHR mode of the PCD, showing both native pixels (blue) and UHR pixels (red).

Yu, SPIE JMI, oct 2016
Leng, SPIE JMI, oct 2016
• The photon counting detector consisting of 30 modules with 128x64 quadratic sub-pixels of 225μm pitch.
• Every sub-pixel features two individually adjustable energy thresholds, enabling contrast-optimization and multi-energy scans.
Images of the temporal bone specimen scanned with (a) EID UHR and (b) PCD UHR modes. Lower noise can be appreciated in the PCD image. The malleus head and incus body are well visualized (arrow heads).

Leng, SPIE JMI, oct 2016
“Measurement of in-plane spatial resolution. For each subsystem, there was no noticeable difference in the measured MTF curves between 80 and 420 mA, indicating consistent in-plane spatial resolution across different tube currents.”

“Normalized product of noise and square root of tube current. The normalized product for the EID subsystem was >1 at low tube currents, which is evidence of electronic noise. The normalized product for the PCD subsystem was 1 for tube currents between 80 and 540 mA.”
VII.A – CT outline

A) X-ray Computed Tomography

1. Basic Concepts
2. Historical Developments
3. X-ray Source
4. Detectors
5. Multi-slice scanners
6. Recent Advances
7. Cone beam systems (9 slides)
8. Tomosynthesis systems
Cone beam mCT was developed by Lee Feldkamp (left) for industrial inspection and used by Michael Parfitt (right) to examine embedded bone specimens from the iliac crest.

- Lee Feldkamp, Ford Motor Co.
- Mike Parfitt, Henry Ford Health
- Steve Goldstein, Univ. of MI

Feldkamp, Davis & Kress
JOSA 1984

“A convolution-backprojection formula is deduced for direct reconstruction of a three dimensional density function from a set of two-dimensional projections.”

Feldkamp, Goldstein & Parfitt
J. Bone & Mineral Res. 1989

“We describe a new method for the direct examination of three-dimensional bone structure in vitro based on high-resolution computed tomography (CT)”
VII.A.7 - mCT: specimen systems

Cone beam mCT laboratory system (hfhs) with micro focus source (left), specimen rotation stage (Ctr.) and flat pane detector (right). Components are installed on a granite bench with tracks to adjust distances and set the geometric magnification.
Specimen and industrial cone beam CT system rotated the object about a single axis. The object region of interest was recorded at many angles using a single large area detector.

- For patients and live animals, this has been extended to keep the object stationary and rotate the detector.
- Cone beam systems use a single large detector and broad beam to record in a single axial rotation.

Cone beam CT systems are now commercially available for animal research in pre-clinical research studies.

Systems use flat panel digital radiography detectors capable of acquiring images in rapid sequence (30 fps).

Volumetric Scan of a mouse thorax (50 micron voxel)
VII.A.7 - Dental / ENT CT systems

• Cone beam systems are now commonly used for dental implant services and Ear Noise and Throat (ENT) diagnosis.

• The Xoran miniCat system uses a flat panel CsI indirect DR detector (Varian PaxScan)

• Xoran Technologies, Inc. was founded in 2001 by two research scientists from the University of Michigan with the goal of developing common sense, innovative technologies that enable physicians to treat their patients more efficiently and more effectively.

• In the past ten years, they have installed more than 400 CT scanners domestically and internationally.
VII.A.7 - Dental / ENT CT systems

3D Dental images, Instrumentarium Dental

VII.A.7 - Angiography cone beam CT systems

Siemens Artis zeego syngo Dyna CT

Right: Robotic arms are now used to move an x-ray tube and angiographic rapid sequence detector in a circular orbit for cone beam tomography. Left: Vessel supplying blood to a chest tumor.
Right: Robotic arms are now used to move an x-ray tube and angiographic rapid sequence detector in a circular orbit for cone beam tomography. 

Left: Vessel supplying blood to a chest tumor.

http://equine4ddi.com/
VII.A.7 - Scatter in Cone Beam Systems

- The broad beam used in cone beam CT systems results in scatter radiation that reduces contrast in the projection views.
- The reconstructed value and the contrast of targets objects is reduced as a consequence.

\[ \mu'd = \mu d + \ln \left( \frac{1}{1 + \frac{S}{P}} \right) \]

A) **X-ray Computed Tomography**

1. Basic Concepts
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8. **Tomosynthesis systems (10 slides)**
VII.A.8 - Tomosynthesis

- **Cone Beam Tomo**
  CB CT systems typically acquire data from large area detectors rotating in a circular orbit for a rotation angle of 360°.

- **Tomosyntheses**
  For tomosynthesis systems, an approximate inverse solution is deduced from data obtained over a limited rotation angle.
  The reconstruction has limited depth separation, but high spatial resolution.
VII.A.8 - Tomosynthesis: Shimadzu Sonialvision / Safire

- The Shimadzu Sonialvision / Safire system integrates the digital detector within a radiographic tilt table.

- Shown in the tilt position for a lateral knee tomosynthesis acquisition (60°), the detector translates up and the x-ray tube moves downward.

- The x-ray central beam is directed at the joint surface with an angle that varies from -20 to +20 degrees.
VII.A.8- Tomosynthesis: GE VolumeRAD

• For the GE VolumeRAD system, the tube angle changes as the tube mount moves linearly.
• The detector remains in a stationary position.
VII.A.8- Tomosynthesis: Siemens breast TS

Tomosynthesis systems designed for breast imaging have been shown to be effective for early diagnosis of breast cancer.
Filtered Backprojection

- The reconstruction is similar to cone beam CT but with a limited acquisition angle.
- The tomosynthesis image quality can be understood from the Fourier representation of the acquired data.

A. High signal frequencies in the x,y directions provide in-plane detail.
B. Varied filter cut-off frequencies vs angle limit Z signal resolution.
C. Flat surfaces are not sampled along the $\omega_z$ direction.
VII.A.8 - Tomosynthesis: 3D spatial frequency domain

**TS vs CT**

Unsampled frequencies along the $\omega_y$ axis make TS and CT complimentary.
VII.A.8 - Tomosynthesis: knee AP view

AP view obtained with toe in and hip elevated with a boomerang filter.

Gazeille, Flynn, Page et.al.
Skeletal Radiology
07 Aug 2011 (online)
TS images are in a plane through the head, neck, and shaft.
Tomosynthesis showed a transverse fracture from the trochanter through the base of the neck.

The patient was sent to surgery for a hip screw.
Conventional mammogram (2D) versus breast tomosynthesis (3D).

When used with FFDM, DBT has been shown to improve cancer detection and reduce callbacks for additional examinations.