Applications of Image Processing and Registration in Medical Imaging: Breast Imaging

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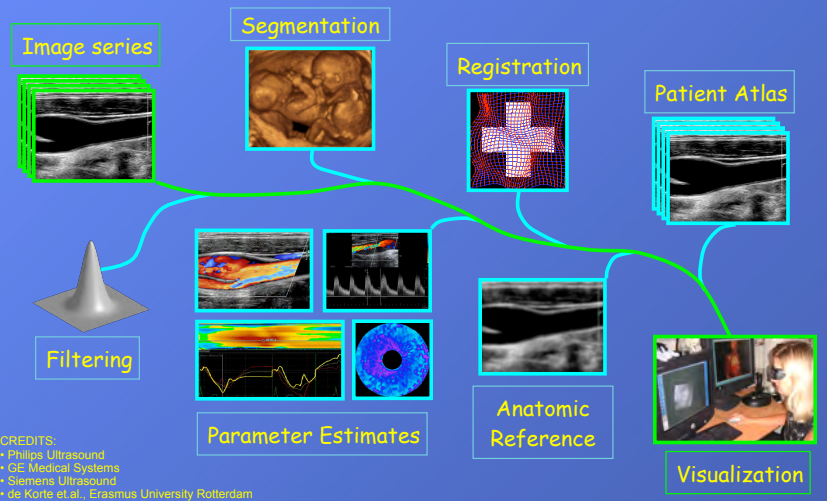
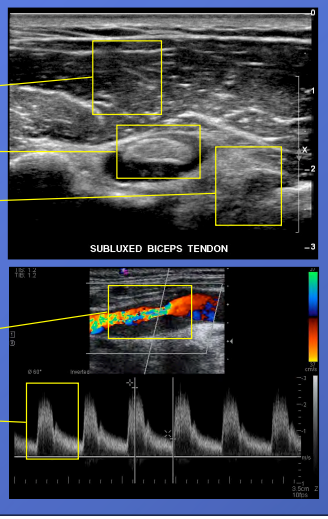
Strategic Organization of Image Processing



CREDITS:
- Philips Ultrasound
- GE Medical Systems
- Siemens Ultrasound
- de Korte et.al., Erasmus University Rotterdam

- Anatomic
  - Intensity
  - Shape
  - Speckle pattern
- Functional
  - Motion
  - Temporal variation
  - Tissue properties



BENG 280B

Comparative Biomedical Imaging
Spring Quarter 2009

Course website: http://webct6web.ucsd.edu

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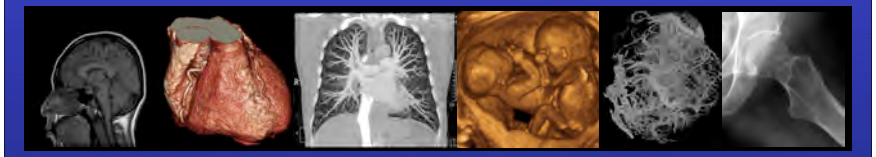
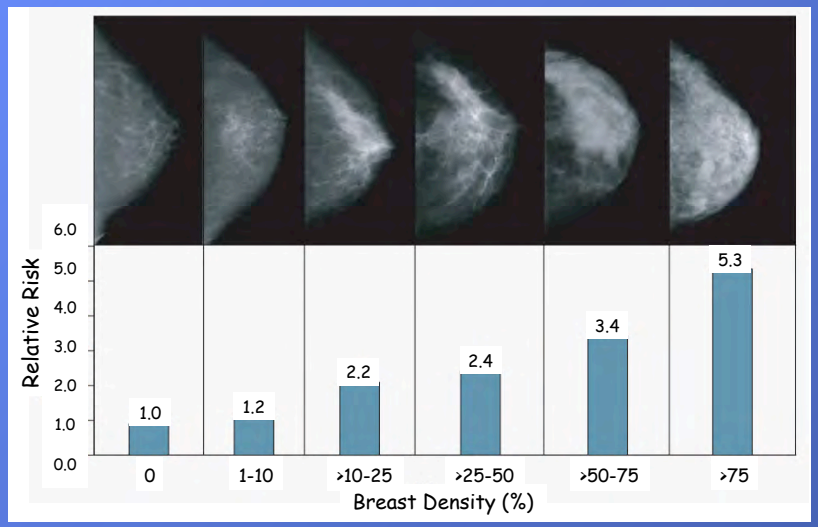


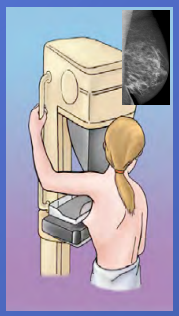
Application of biomedical imaging to the measurement of structure, function, and dynamics of organ systems from the microscopic to the organ level. Emphasis on detailed evaluation and comparison of specific imaging modalities.

Breast Cancer Risk



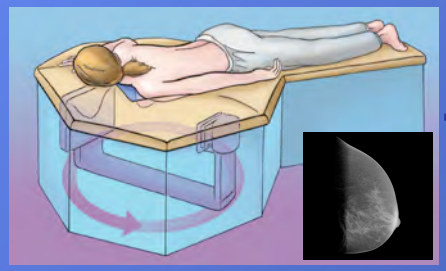
Background:

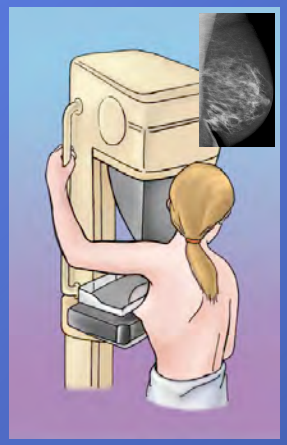
- One in 6 women will develop breast cancer
- Early detection is the most important factor for survival
- Most cancers arise in dense ductal tissue
- Mammography is the "gold standard" but dense breasts are a challenge
- Volume imaging (bCT or VBUS) improves lesion localization
- Precision localization improves biopsy results, especially for small lesions
- Robotic devices may provide more precise device placement



Breast Imaging

- Tomographic slices
- Pendant breast
  - less discomfort
  - better resolution





Building a Breast Imaging Machine

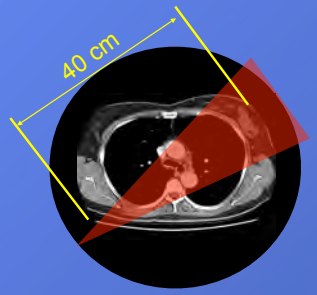
Breast CT - Design / Construction
- System Modules
- Acquisition
- Reconstruction

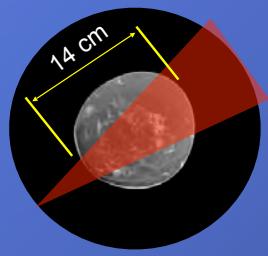
Breast Ultrasound - Design / Construction
- System Modules
- Acquisition
- Reconstruction

Mammogram Simulation
- Classification & Extraction
- Compression

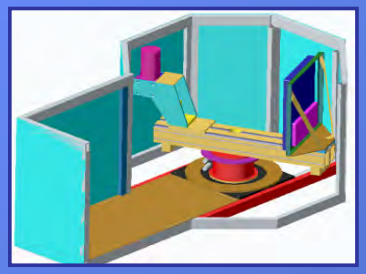
Tissue Parameter Estimation

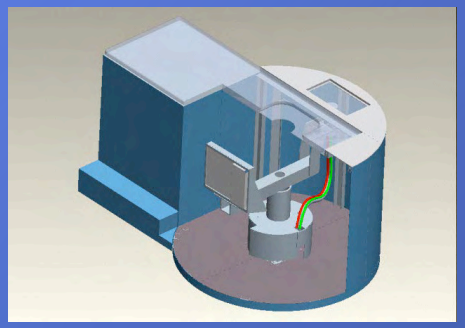
Image-Guided Robotic Biopsy





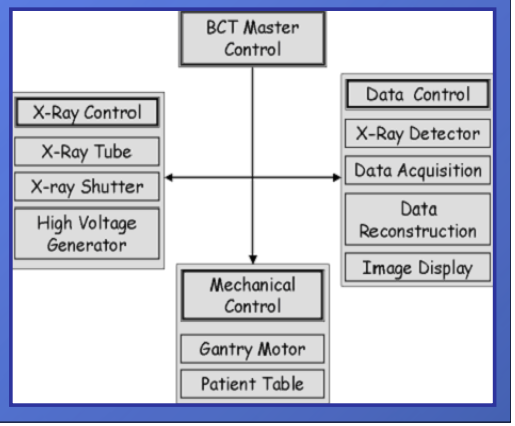
Breast CT Scanner Design - CAD Engineering





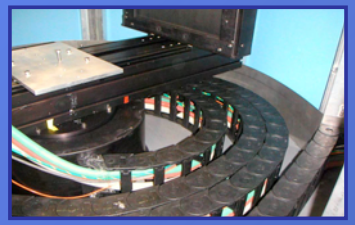
System Control Modules

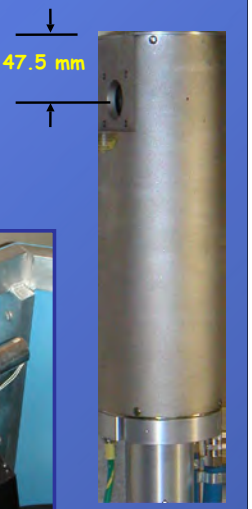
- interface all sub-systems to master control
- position synchronization
- control timing
- control x-ray on
- interlocks
- acquisition control



X-ray tube & power supply

- 100 kVp 6.4 mA --> 0.7 kW generator
- 0.4 mm x 0.4 mm focal spot
- Be window
- water cooled heat exchanger
- high voltage cables
- grounding rod





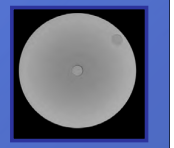
X-ray detector
- Solid-state Cs(I)
- TFT detector
  - 1x1: 2048 x 1536
    - 0.194 mm pixels
    - 60 frames per second
  - 2x2: 1024 x 768
    - 0.388 mm pixels
    - 30 frames per second
  - 2x4: 1024 x 384
    - Dual Gain Mode
    - 30 frames per second

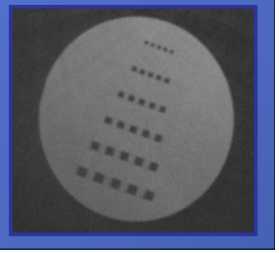
Gantry motion
- motor control (angle & motion)
- interface with x-ray
- interface with detector
- support x-ray tube
- support detector
- precise angular control

Kollmorgen Servo Motor
DDR D081M
13.0 ft-lb continuous torque
32.0 ft-lb peak torque

Patient support
- provide comfortable support for patient
- provide close access to chest wall
- support weight of large patients

Data acquisition and analysis
- acquire images through 2π geometry
- incorporate system calibration parameters
- correct images errors
  - non-linearity
  - pixel drop-out
- perform weighted back-projection algorithm
- correct slices to CT numbers
- provide image orientation
- provide image position





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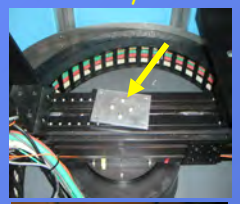
stationary stand



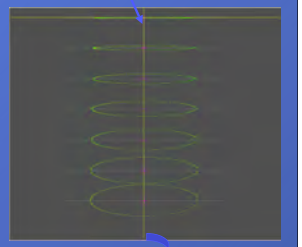
Pb shot in foam board

BB tracker

path of BBs in sinogram

BB paths are fit to analytical functions that define CT geometry

central ray



rotation of detector

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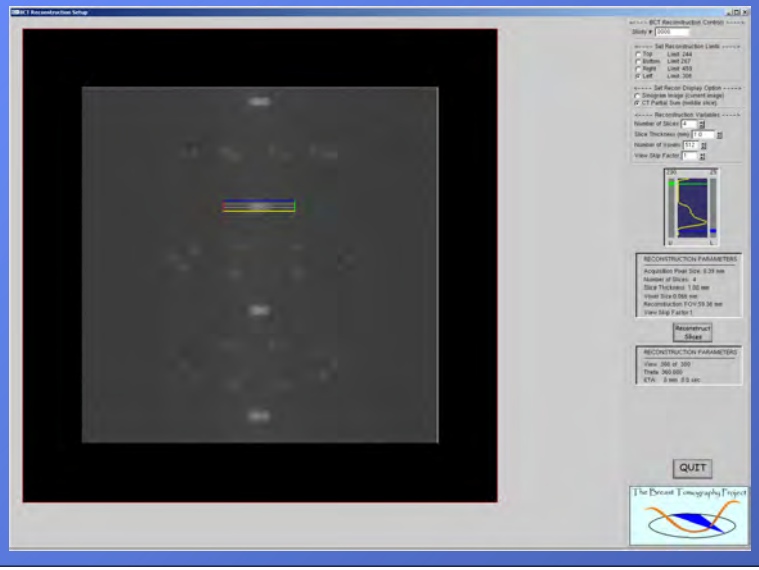

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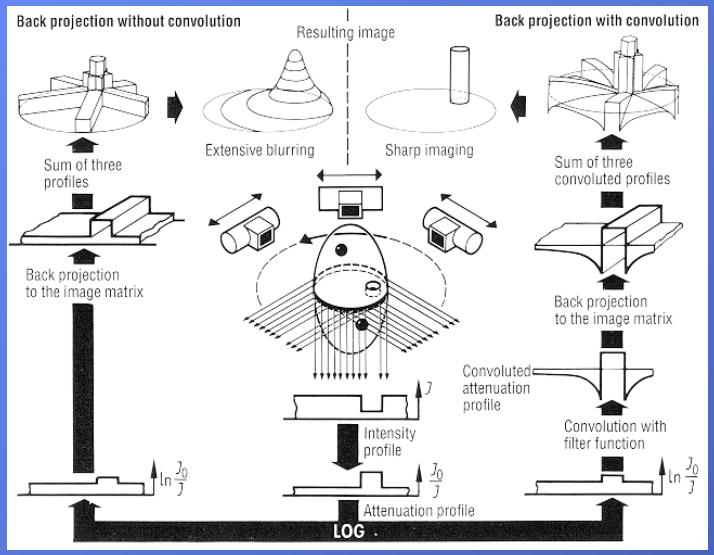

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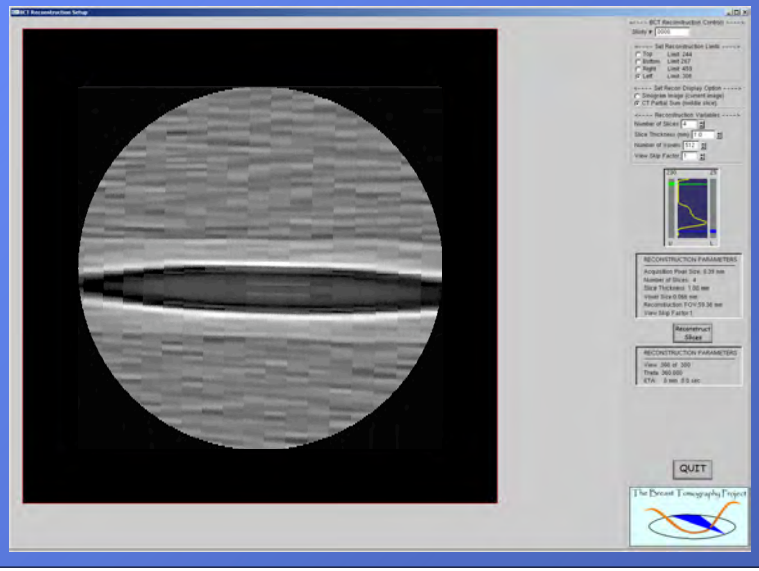
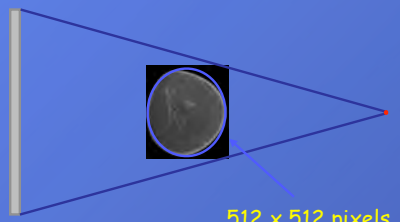


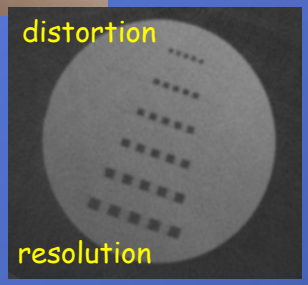


768 x 1024 pixels
500 views

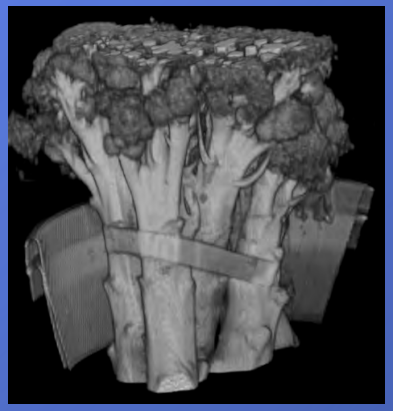
512 x 512 pixels
300 slices ~(0.5 mm)

Reconstruction Based on Feldkamp Algorithm
(written in C)

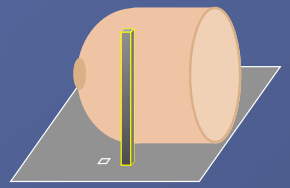
Subjective Assessment



The Broccoli Test



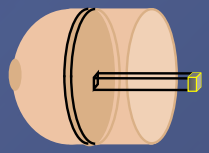
mammography



0.10 mm x 0.10 mm x 50 mm

= 0.50 mm^3

breast CT

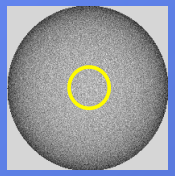


0.25 mm x 0.25 mm x 0.50 mm

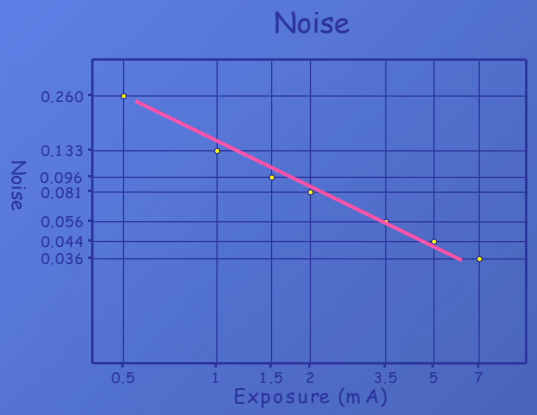
= 0.03 mm^3

Breast CT voxels are 16x Smaller Than Mammography

Noise Assessment

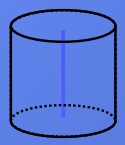


Air Scans

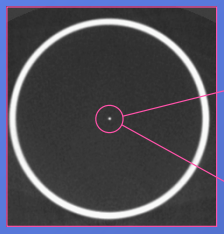


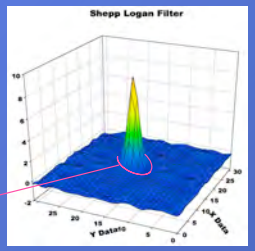
Spatial Resolution

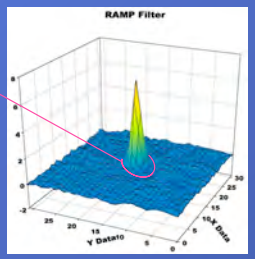
geometric magnification
detector pixel size



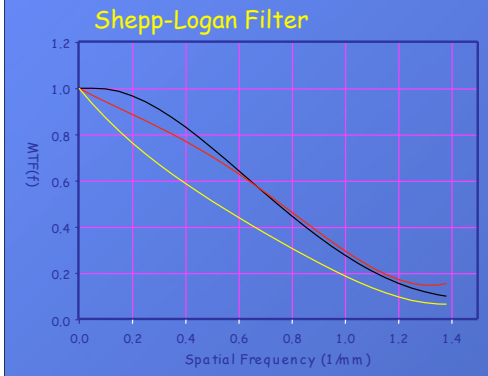
70 µm nickel-chromium wire

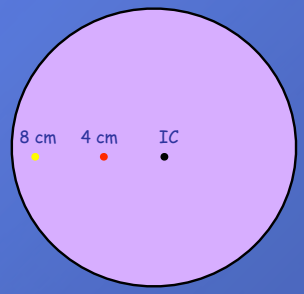






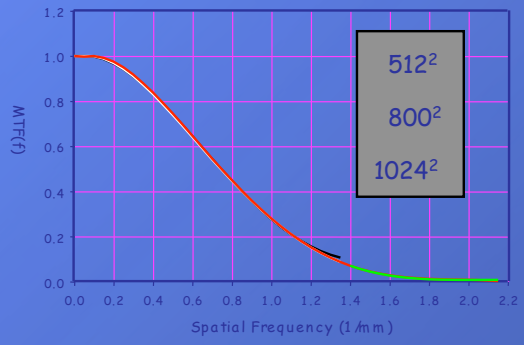
Spatial Resolution





1000 views recon to 512^2 matrix
influence of FOV position

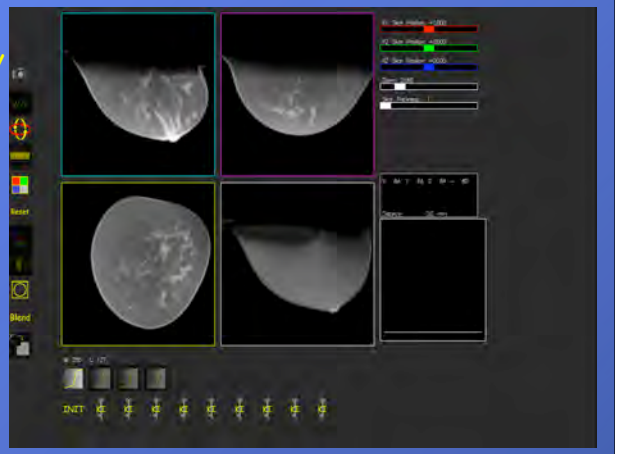
Spatial Resolution

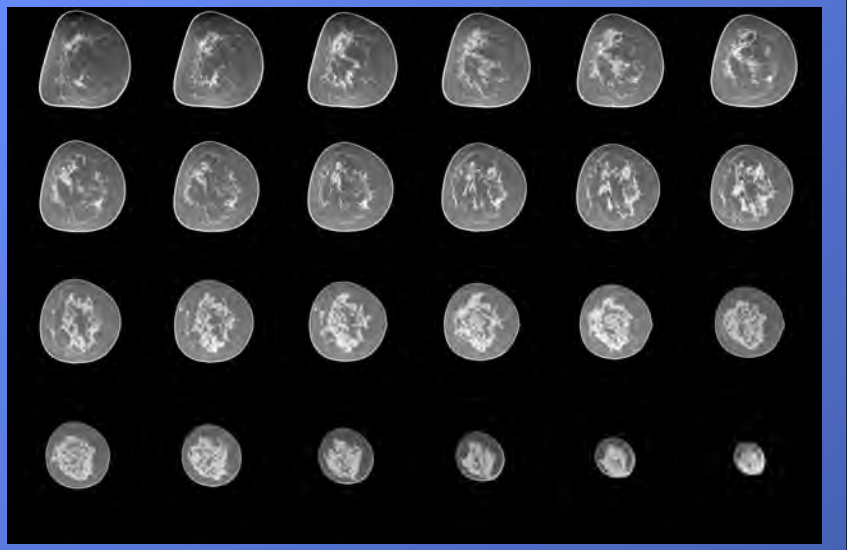


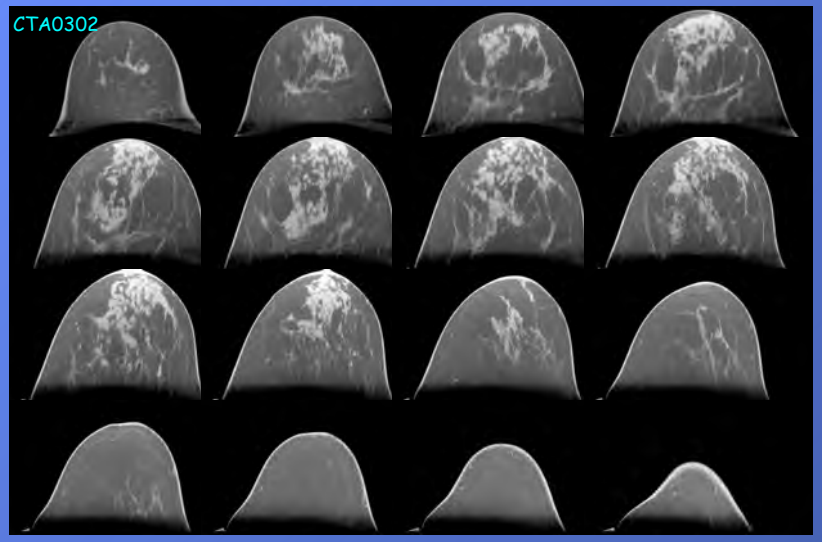
1000 views
influence of reconstruction matrix

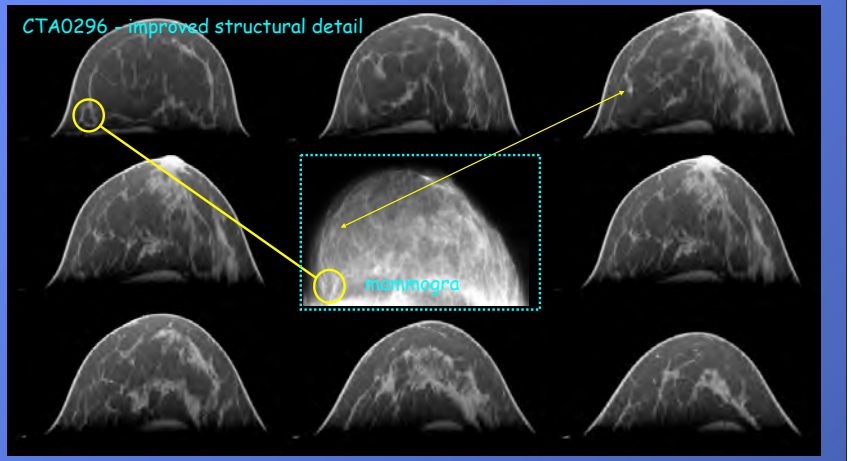
Visualization

- slices
- rendering
- interactivity









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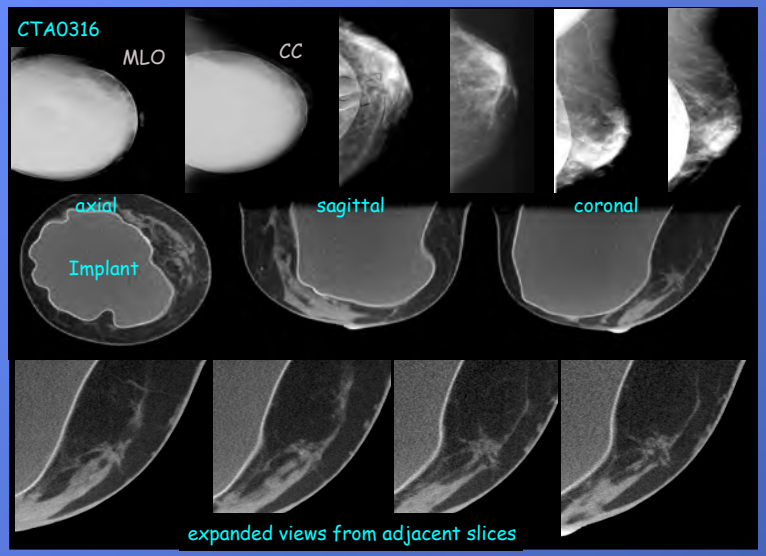

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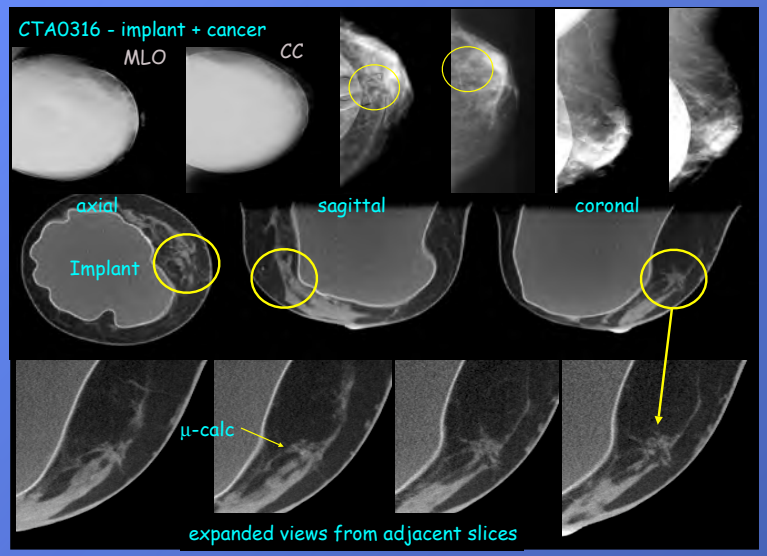

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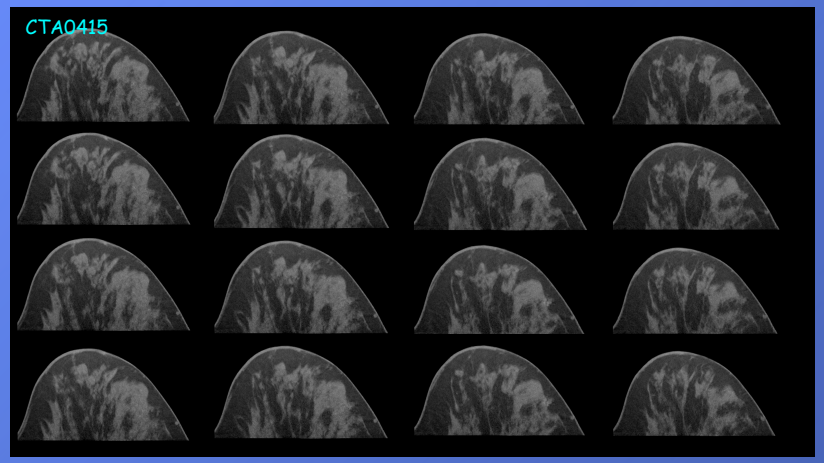

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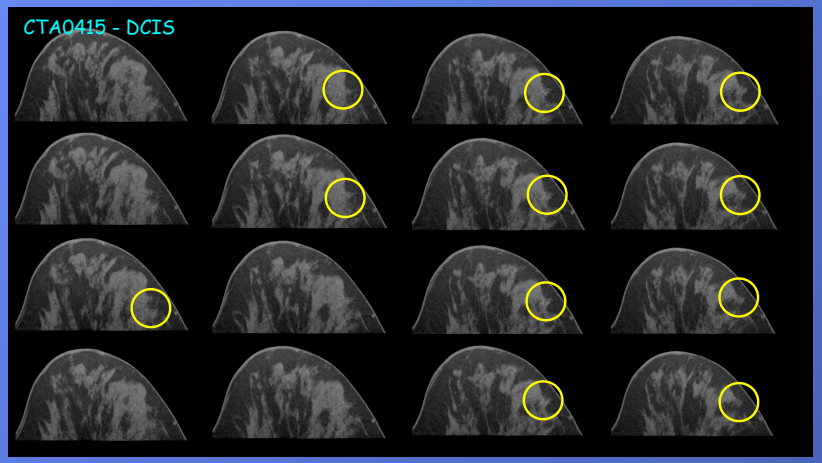
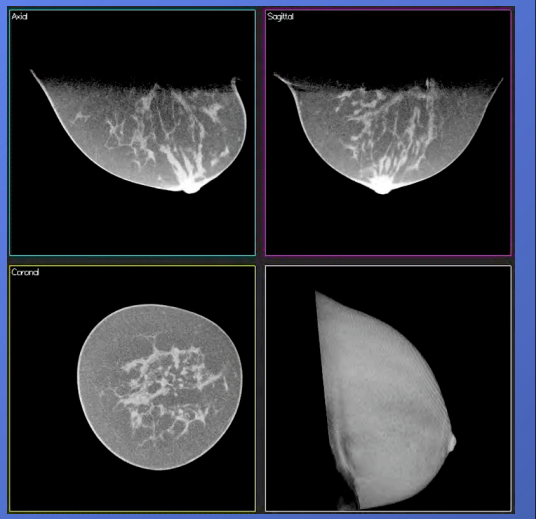


Visualization

- slices
- volume rendering
- interactivity



Building a Breast Imaging Machine

Breast CT - Design / Construction
- System Modules
- Acquisition
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Breast Ultrasound - Design / Construction
- System Modules
- Acquisition
- Reconstruction

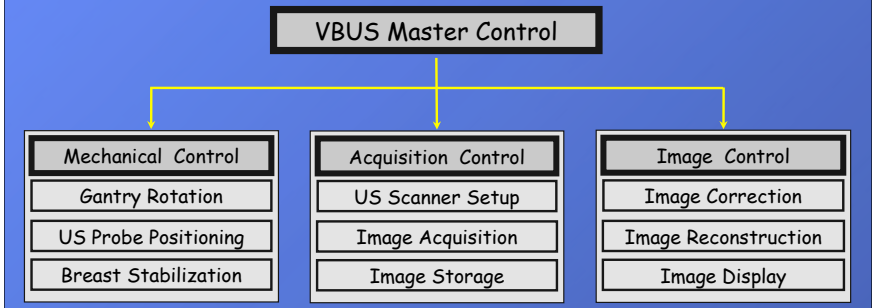
Mammogram Simulation
- Classification & Extraction
- Compression

Tissue Parameter Estimation

Image-Guided Robotic Biopsy

Design Strategy:
- Image pendant breast
- Use clinical US scanner with high frequency probe
- Stabilize breast without compression
- Automate scan acquisition
- Integrate with breast CT scanner

Performance Parameters Evaluated:
- Spatial and contrast resolution
- Image acquisition time
- Image compounding and speckle reduction
- Volumetric data display
- Evaluate series of test objects
- Evaluate volunteers



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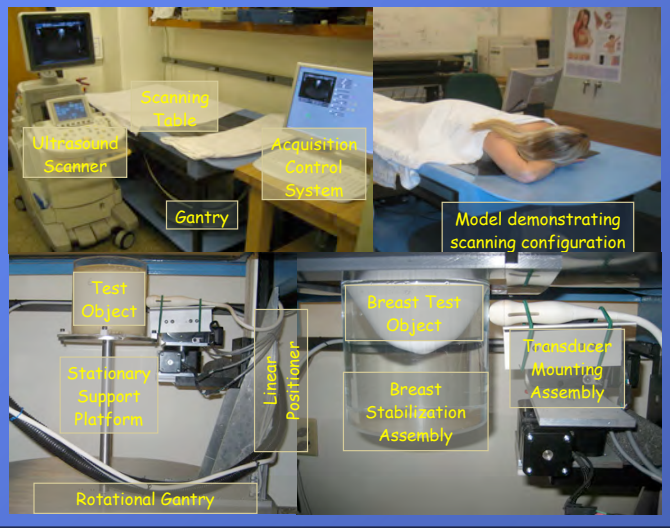

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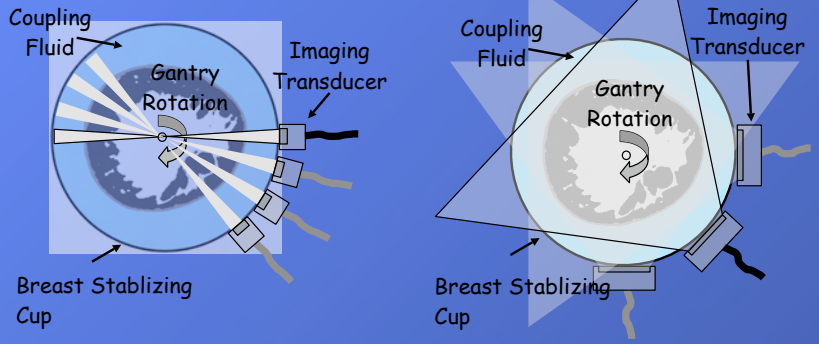

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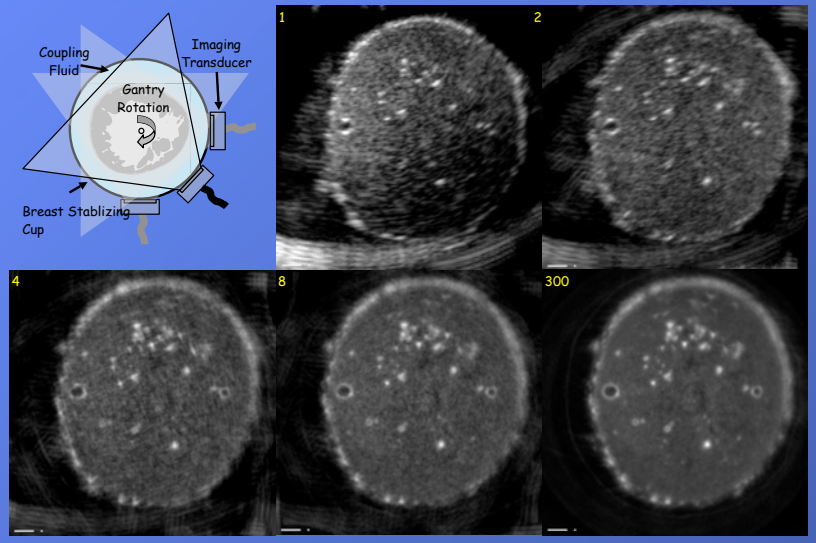

Applications of Image Processing and Registration in Medical Imaging

Results:

- Scan acquisition fully automated
- Scan time 18 sec at 20°/sec
- Pendant geometry provides good visualization of entire breast
- Slice reconstruction time < 100 ms using GPU
- Volume reconstruction time < 5 sec using GPU
- Slice images compare favorably with Breast CT
- Spatial resolution ~ 1 mm
- Volume breast data reviewed on volume workstation

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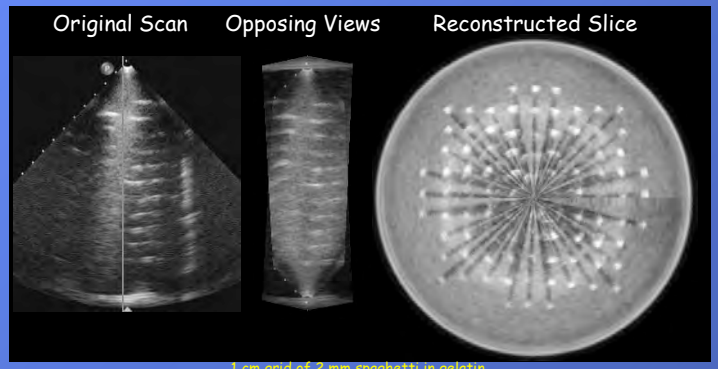

1 cm grid of 2 mm spaghetti in gelatin

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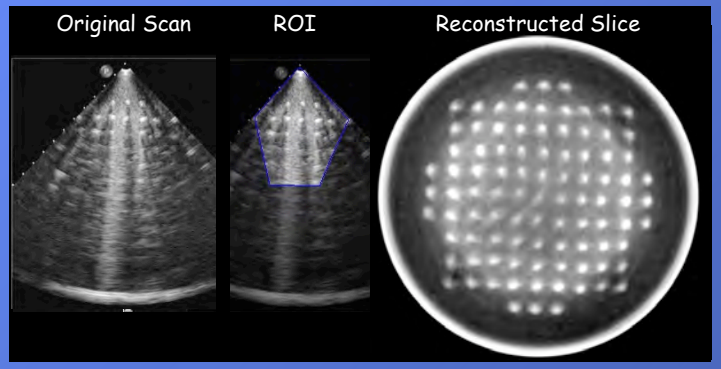
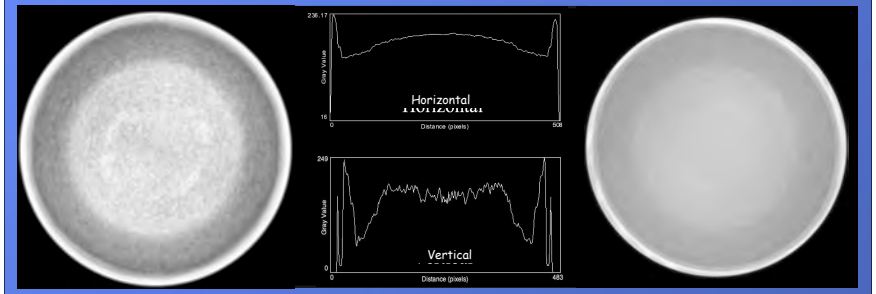


1 cm grid of 2 mm spaghetti in gelatin

Applications of Image Processing and Registration in Medical Imaging

Vertical Scan

Horizontal Scan

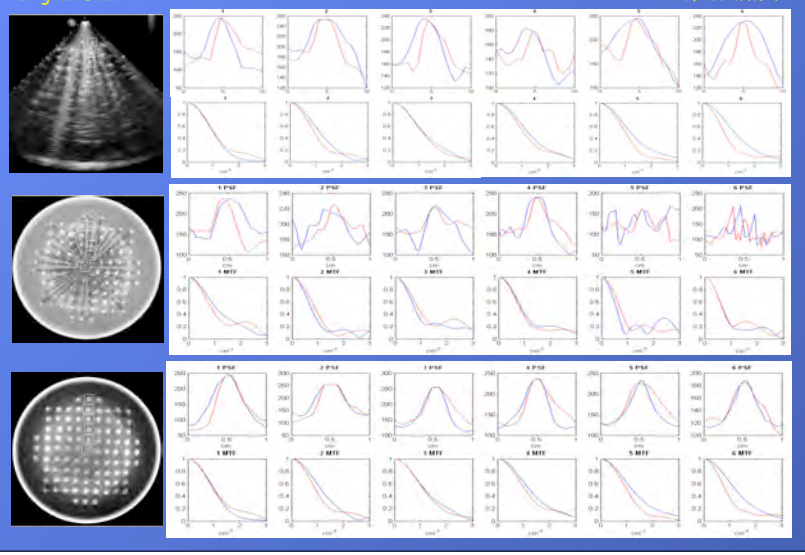


Acquisition Orientation	Mean	Sigma	S/N
horizontal	193	2.8	70.2
vertical	215	10.8	20.0

Applications of Image Processing and Registration in Medical Imaging

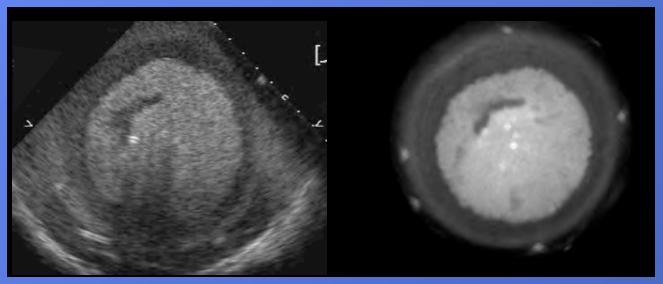
Original Scan

Profiles & MTF



Low Contrast Test Objects

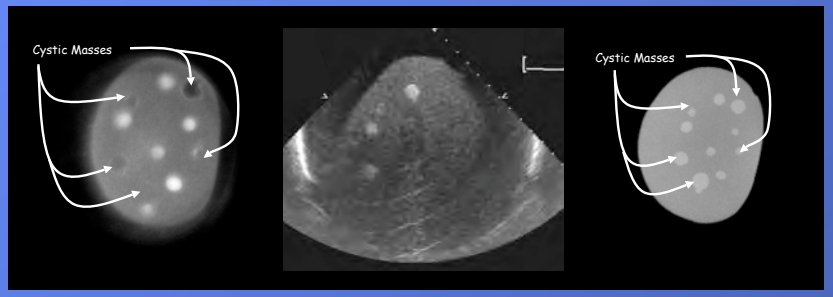
Original US Scan | VBUS Scan



Gelatin Test Object

VBUS Comparison to Breast CT

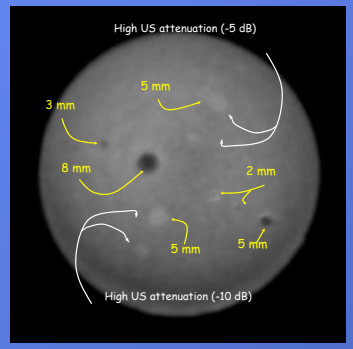
VBUS Scan | Original US Scan | Breast CT



Breast Test Object (051, CIRS, Norfolk, VA)

Low Contrast Test Objects

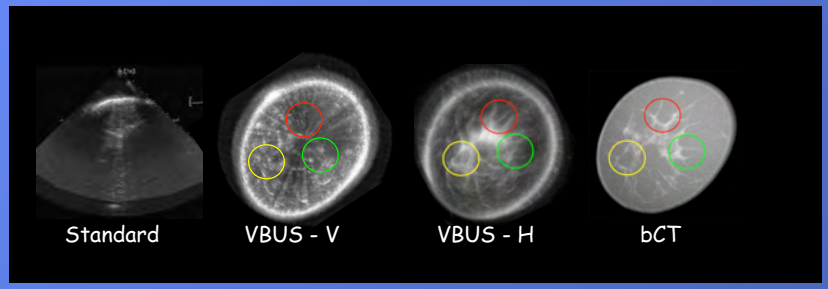
VBUS Scan



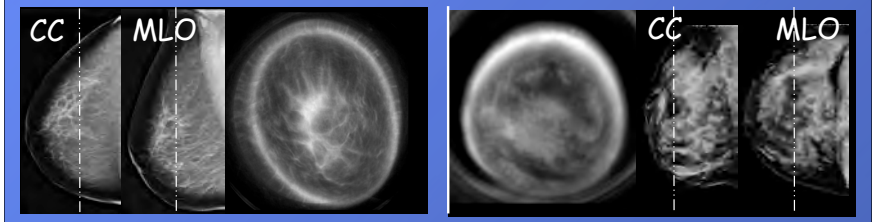
BACKGROUND:	F1677
Speed of Sound:	1434 m/s
Attenuation:	0.5 dB/cm/MHz
Contrast:	-10
Temperature:	22.2°C
Cylindrical Targets 1:	F1680
Speed of Sound:	1466 m/s
Attenuation:	1.31 dB/cm/MHz
Contrast:	-10 dB
Temperature:	22.0°C
Cylindrical Targets 2:	F1681
Speed of Sound:	1427 m/s
Attenuation:	0.93 dB/cm/MHz
Contrast:	-5 dB
Temperature:	22.2 °C

Urethane (CIRS, Norfolk, VA) Test Object
(courtesy Dr. M. Andre)

Volume Breast Ultrasound



Volume Breast Ultrasound

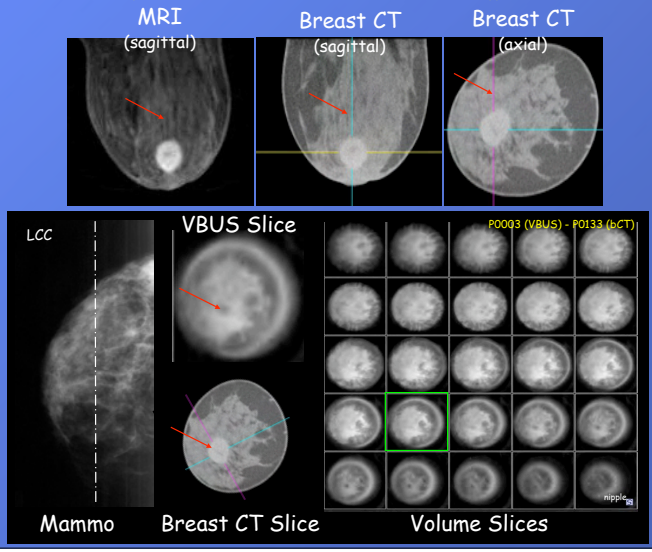


Fatty Replacement Breast

Fibro-Glandular Breast

P0001(L) & P0002 (L)

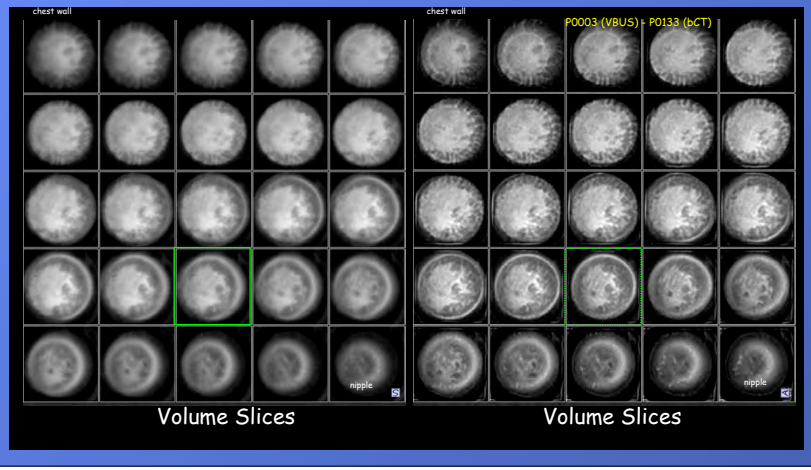
Fibro-Glandular Breast with Tumor



Original

Deconvolution

(Gaussian and point-spread-function)



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  - Compression
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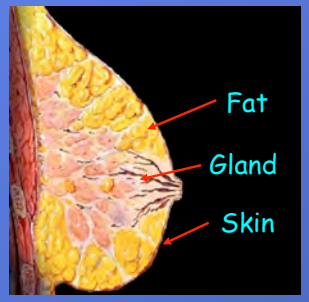
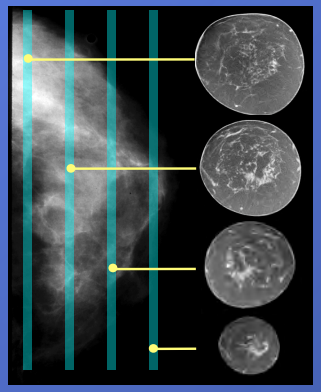
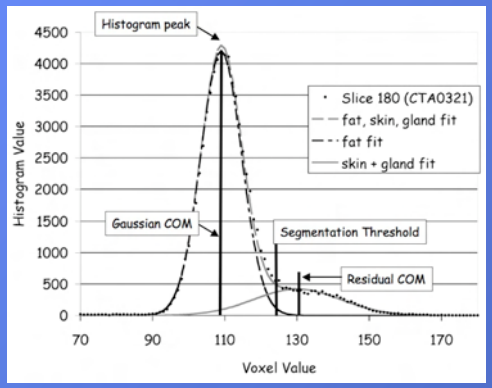
- Image-Guided Robotic Biopsy

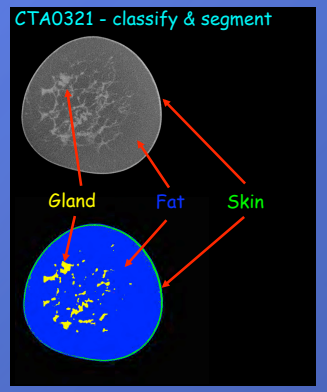
Analysis

- segmentation & classification
  - histogram analysis
  - region growing
- quantification
  - skin
  - fat
  - gland

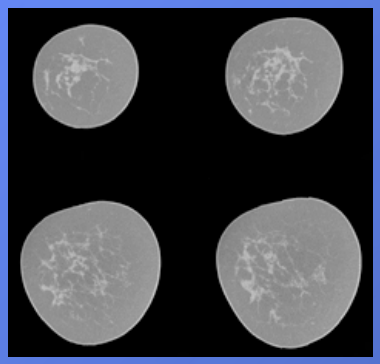




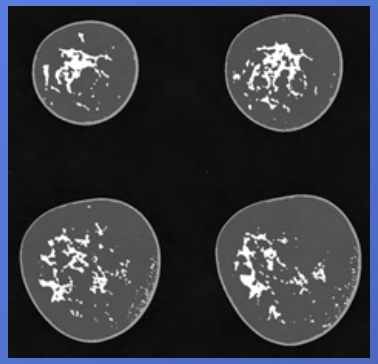


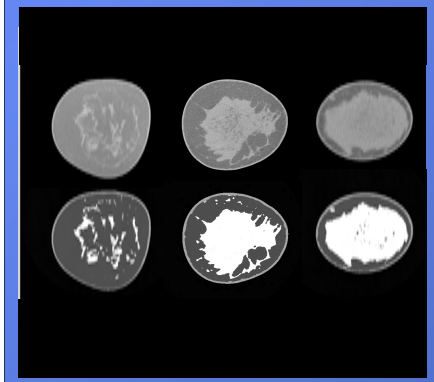


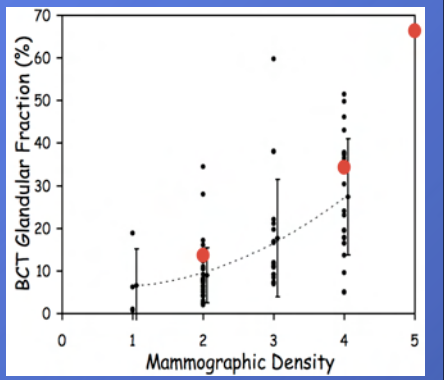
Original

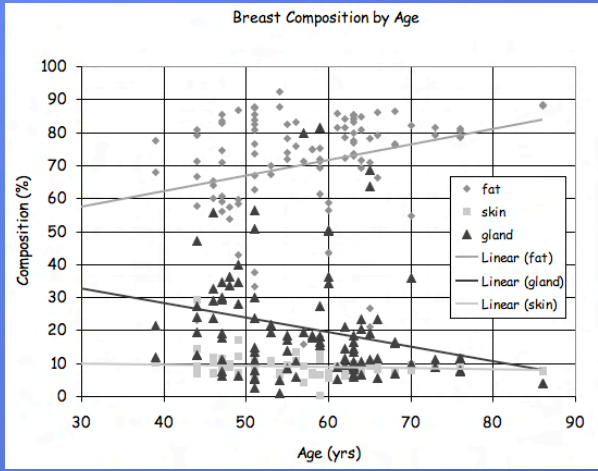


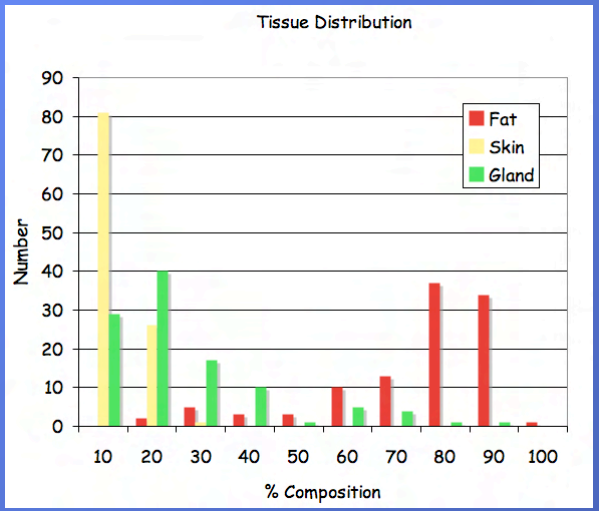
Segmented

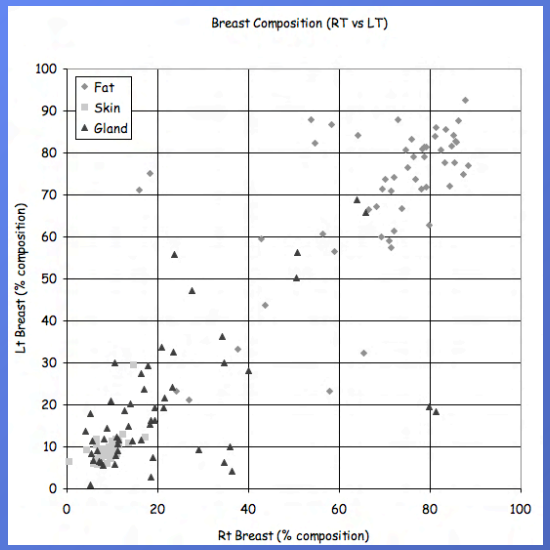


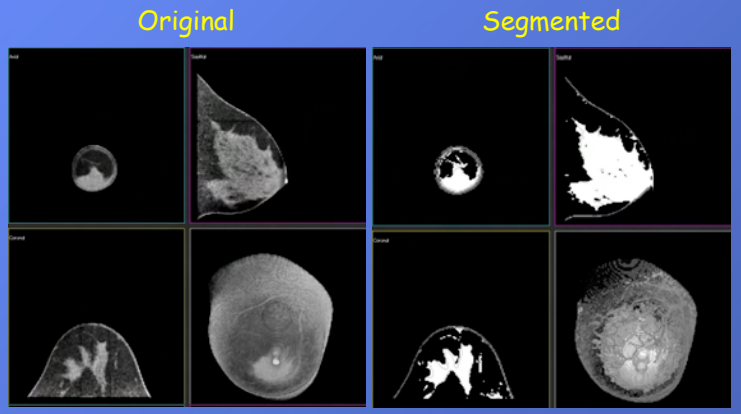





Breast Composition by Age
Composition (%)
Age (yrs)
fat
skin
gland
Linear (fat)
Linear (gland)
Linear (skin)


Tissue Distribution
Number
% Composition
Fat
Skin
Gland


Breast Composition (RT vs LT)
Lt Breast (% composition)
Rt Breast (% composition)
Fat
Skin
Gland


Original
Segmented

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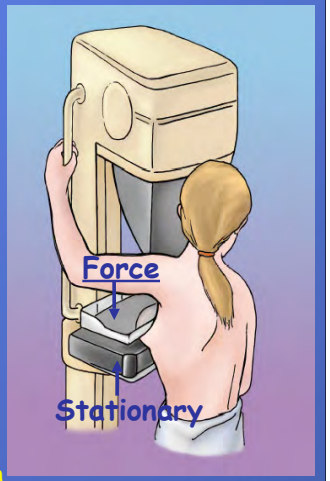
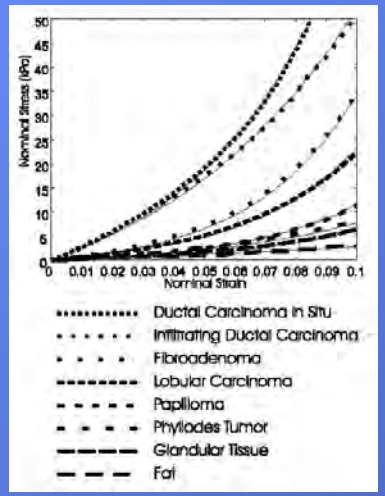
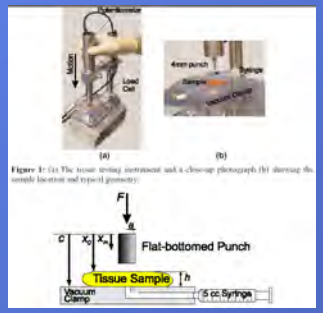
  - Compression
- Tissue Parameter Estimation
- Image-Guided Robotic Biopsy

Primary challenges to simulate mechanical compression of the breast:

- describe the mechanical properties of breast tissue
  - tissues present
  - proper classification
  - mechanical coefficients for each tissue
- select the appropriate numerical model
- describe the contact between the
  - compression paddle and the breast skin
  - mammography unit and the breast skin



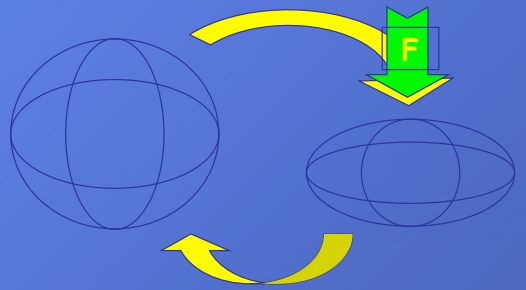





Breast Tissue Stiffness in Compression is Correlated to Histological Diagnosis

Numerical Compression Methods:

- Evaluated various approaches to compression
  - Forward approach – Finite Element Analysis
  - Inverse approach – registration / transform

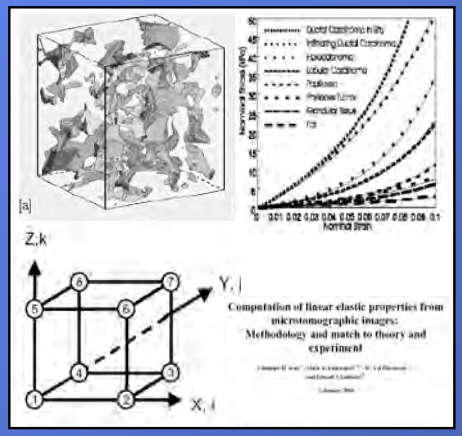


Numerical Compression Methods: Finite Element Analysis

- Challenges
  - Mesh generation
  - Mesh complexity
  - Computational time
- Benefits
  - Accurate simulation
  - Results may be generalized for rapid computation
  - Physical parameters may be extracted from solution

Methods

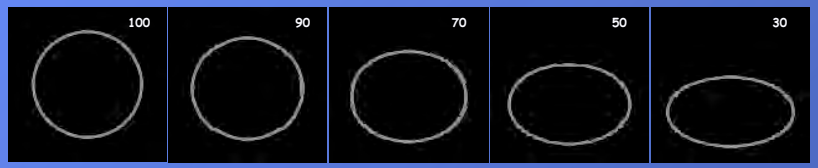
- Finite Element Analysis
- Challenges
  - Computational time
  - Mesh generation
  - Mesh complexity



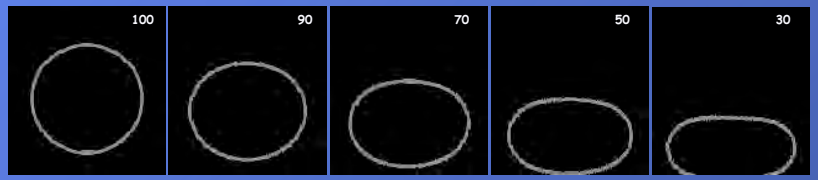
- Use techniques of Garboczi et.al. to solve the equations in a random linear elastic material, subject to an applied macroscopic strain, using the finite element method.

Simple Compression - Sphere Shell

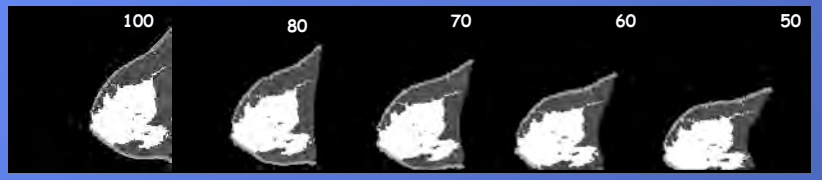
Sphere shell (Young's Modulus - 2 kPa - Medium 2 kPa)



Sphere shell (Young's Modulus - 90 kPa Meduim 2 kPa)

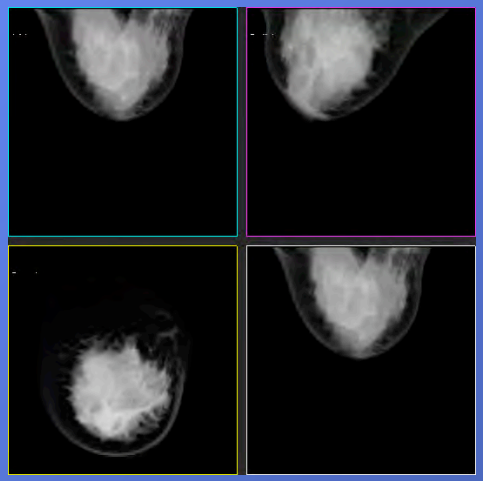


Simple Compression - Breast (segmented)

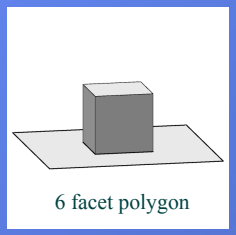


Breast(segmented) (Young's Modulus - skin 90 kPa, Gland 10 kPa, Fat 1 kPa, Meduim 1 kPa)

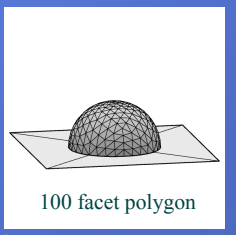
Breast segmented Young's Modulus



- Droplet on Plane Surface:

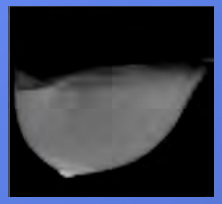


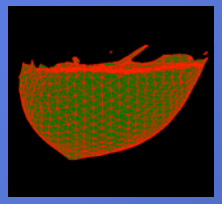
6 facet polygon



100 facet polygon

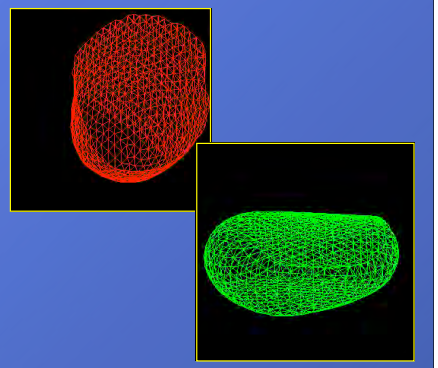
- Incorporating gravity and surface contact energy

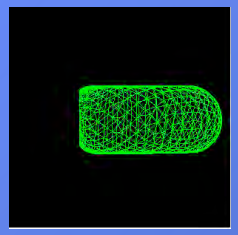


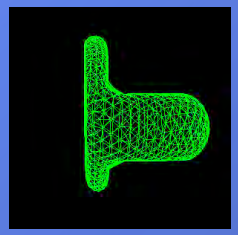


- Surface is fit by tetrahedral elements
  - Used voxel data threshold value
- Mesh is generated by marching tetrahedra algorithm
  - http://en.wikipedia.org/wiki/Marching_tetrahedrons
  - G. M. Treece, R. W. Prager, and A. H. Gee. Regularised marching tetrahedra: improved iso-surface extraction. Computers and Graphics, 23(4):583--598, 1999

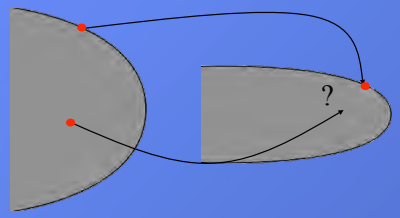
- Interior treated as incompressible fluid
  - volume preserved
- Chest wall vertices remain in a plane
- Impose various constraints
  - Pointwise:
    - Fixed vertices
    - Level set constraints
    - One-sided constraints
      - nonpositive or non negative vertex function
  - Global:
    - Volume constraint
- Apply compression

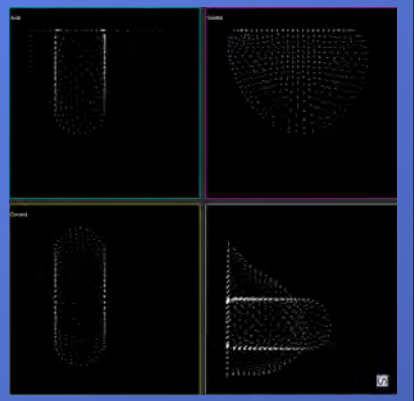






- Compression plates can be simulated in different ways
  - Top: entire breast is compressed
  - Bottom: major portion of breast compressed





- Surface point displacements
  - Known from mesh surface vertex points
- Interior point displacements
  - Inferred by interpolation from mesh surface vertex points and their compression displacement

- (IWD Interpolation).
- One of the most commonly used methods to interpolate a series of scatter points.
- Assumption: interpolated value is most influenced by nearby points and less by more distant points.
- The simplest form of IWD Interpolation is "Shepard's method"

D. Shepard, A two-dimensional interpolating function for irregularly spaced data. Proc. ACM. nat. Conf., 517--524, 1968

Interpolation point location

Interpolated value $\rightarrow F(x,y,z) = \sum_{i=1}^{n} w_i f_i$

n: number of scatter points in the set

f_i: prescribed function values at scatter points

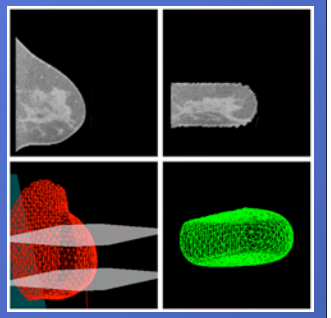
w_i: weight functions assigned to each scatter point

$$w_i = \frac{d_i^{-p}}{\sum_{j=1}^{n} d_j^{-p}}$$

p: real number > 1.0 (here best results with p=4.0)

d_i: distance from scatter point to interpolation point $d_j = \sqrt{(x-x_j)^2+(y-y_j)^2+(z-z_j)^2}$

- Mesh generation
  - Marching tetrahedrons
    - 128^3 voxel volume input
    - Triangles in mesh
      - Vertices: 1620 Edges: 4854 Facets: 3236
  - Interpolation
    - 1620 surface points and displacements



- Compression Computation Time
  - Surface Mesh Generation
    - 0.04 sec
  - Surface Compression
    - 1.15 sec
  - Voxel Interpolation
    - 63.13 sec (128^3)
    - 504.3 sec (256^3)

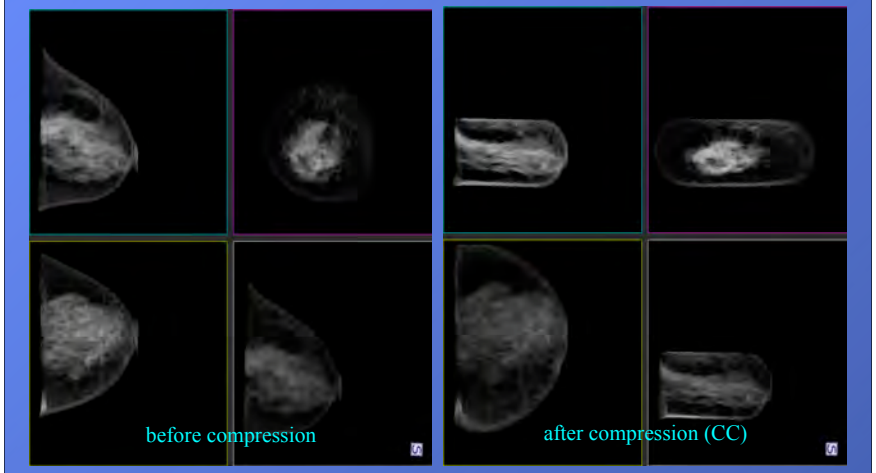


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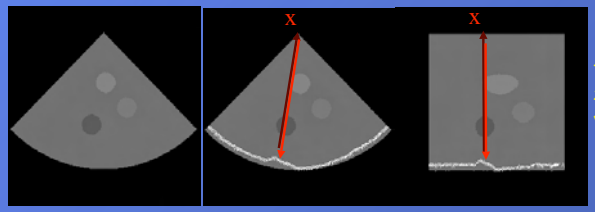
Image-Guided Robotic Biopsy

Sound speed and attenuation:

- Measure time delay (spatial shift) of reflections from back wall
  - delay represents relative change in speed from baseline as sound propagates through different materials
- Time delay converted into per view time delay line
  - no delay equals baseline sound speed
  - shift towards transducer represents shorter time delay
  - shift away from transducer represents longer time delay



time delay = 2 * x / v
x = distance (m)
v = speed of sound assumed by US machine (m/s)

Sound speed and attenuation:

- Use filtered back-projection to construct sound speed image
  - use delays from 360° of acquisition
- Mathematical considerations:
  - Back wall deviations give us time delay

$$time\_delay(x,\theta) = \frac{back\_wall\_shift(x,\theta) + D}{SOUND\_SPEED}$$

  - Time delay is a "projection" of image "slowness"

$$time\_delay(x,\theta) = 2 * \int_0^D slowness(x,y)dy$$

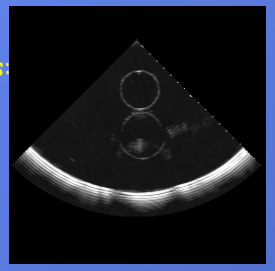
  - Use filtered back projection to reconstruct slowness image

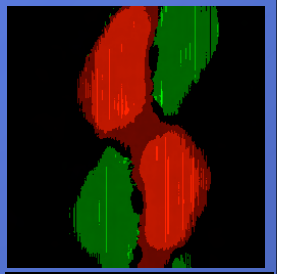
$$slowness(x,y) = \int_0^{2\pi}\int_0^w time\_delay(x\cos\theta + y\sin\theta - t)dtd\theta$$

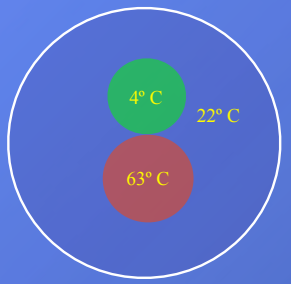
  - Invert slowness image to get sound speed image

$$speed(x,y) = \frac{1}{slowness(x,y)}$$

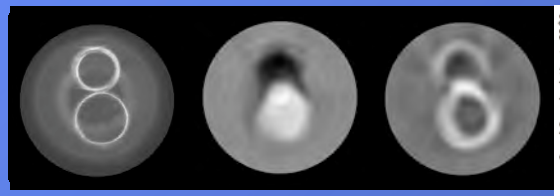
- Experiments:
  - Phantom measurements:
    - temperature variations

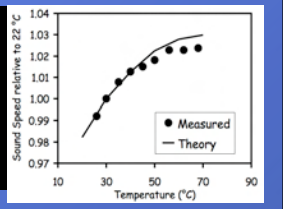






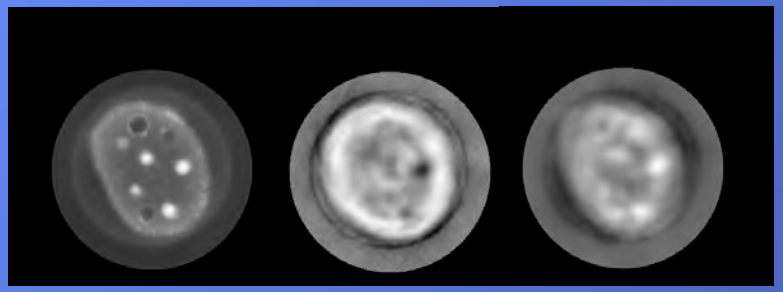
Sound Speed and Attenuation





reflection speed-of-sound attenuation

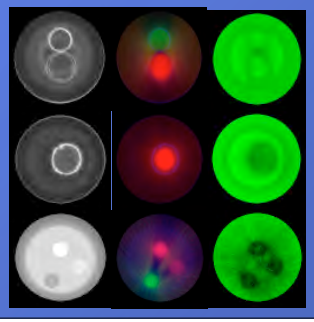
Sound Speed and Attenuation



reflection speed-of-sound attenuation

Conclusions:

- Possible to produce sound speed images with clinical scanners
- Work remains in improving resolution and accuracy
- With further technical improvements may provide sufficient information to assist in improved tissue characterization
  - potential contributions to improving cancer DX



Building a Breast Imaging Machine

Breast CT - Design / Construction
- System Modules
- Acquisition
- Reconstruction

Breast Ultrasound - Design / Construction
- System Modules
- Acquisition
- Reconstruction

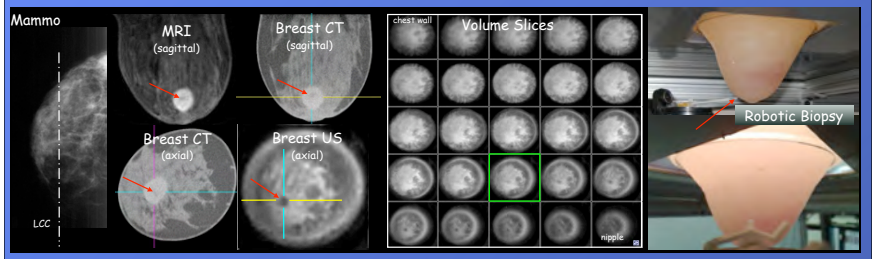
Mammogram Simulation
- Classification & Extraction
- Compression

Tissue Parameter Estimation

Image-Guided Robotic Biopsy

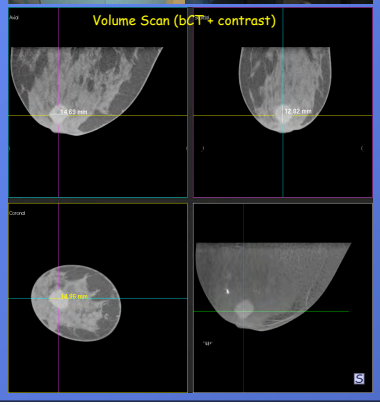
Minimally-Invasive Image-Guided Breast Cancer Detection and Biopsy

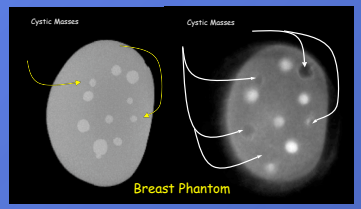
Fibro-Glandular Breast with Tumor

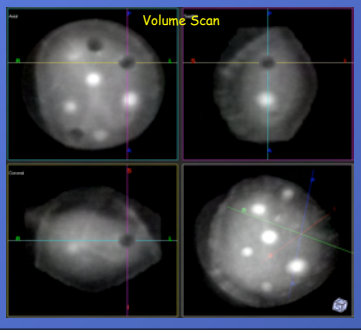


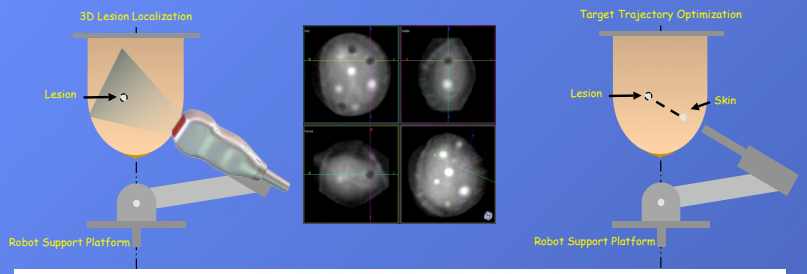
P0003 (VBUS) - P0133 (bCT)

Minimally-Invasive Image-Guided Breast Cancer Detection and Biopsy









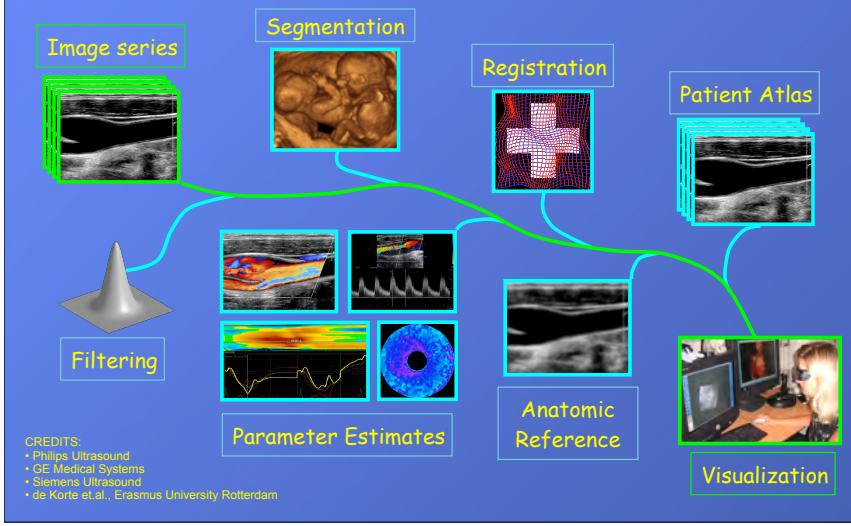
UCSD

Volume Breast Biopsy System (VBBS)

Building a Breast Imaging Machine

- Breast CT - Design / Construction
  - System Modules
  - Acquisition
  - Reconstruction
- Breast Ultrasound - Design / Construction
  - System Modules
  - Acquisition
  - Reconstruction
- Mammogram Simulation
  - Classification & Extraction
  - Compression
- Tissue Parameter Estimation
- Image-Guided Robotic Biopsy

Strategic Organization of Image Processing



Applications of Image Processing and Registration in Medical Imaging: Breast Imaging

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