Image Reconstruction in Optical Tomography:
Utilizing Large Data Sets

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Optical tomography

- Laser
- Detectors
- Computer
- Electronics

[Diagram showing the components of optical tomography with a diagram of a human body in the middle, connected by laser and detector lines.]
Inverse problem

Problem: Given measurements from multiple source-detector pairs, reconstruct the spatial distribution of the optical absorption and scattering coefficients.
Size of the Data Set and Complexity of the Problem

\[ \phi_{ij} = \sum_j \Gamma_{ij,n} \delta \alpha_n \]

\[ i = 1, \ldots, N_s \]

\[ j = 1, \ldots, N_d \]

\[ n = 1, \ldots, L^3 \]

\[ N_s - \text{number of sources} \]

\[ N_d - \text{number of detectors} \]

\[ N = N_s N_d - \text{total number of data points} \]

\[ L^3 - \text{number of volume elements} \]
First generation Penn Scanner (~1995)

- Pulsed laser: 1 mW, 5MHz, 780, 830 nm
- Optical switch
- Attenuator
- Reference channel
- Detector module
- Router
- 8 x 1
- Trigger pulse
- PC - TAC - MCA

~100 source-detector pairs
Philips Scanner (~1998)

~$10^5$ source-detector pairs
Noncontact imager (2005)

$10^8 - 10^{10}$ source detector pairs
QUESTIONS:
• Is it possible to practically use data sets significantly larger than $10^5$ points?
• Is more data better?
• How does the size of data set affect image resolution?
• How does the size of data set influence noise tolerance and image artifacts?

METHODS:
• We have developed image reconstruction algorithms that are capable of utilizing extremely large data sets
• We have built an experimental imager which can acquire $\sim10^8$ data points
Simulations: Relation Between Sampling and Resolution

- Slab geometry with absorbing boundaries (mammography)
- Sampling on square lattice with spacing $h$
- Measurements in window of size $W$
- Assumptions
  - DC
  - physiologic values of background $\alpha, D$
  - point absorbers
  - $L = 6 \text{ cm}$
  - FOV = $6 \text{ cm} \times 6 \text{ cm}$

**Resolution**

- Fundamental limit of transverse resolution is $h$
- Depth resolution determined by numerical precision
Sampling and limited data

Data set size approximately corresponding to our current experimental set up
Noncontact imager

$10^8 - 10^{10}$ source detector pairs
Reconstructions from experimental data

- $10^8$ source-detector pairs
- $10^3$ sources and $10^5$ detectors
- 8 mm diameter black balls in 1% Intralipid
- Balls in midplane of sample
- 50 mm slab thickness
- 2.6 mm slice separation
- 15 cm x 15 cm FOV
Reconstructions from experimental data

FWHM_{xy} = 11 \text{ mm}  
FWHM_{z} = 1.5 \text{ cm}  
Separation = 3.3 \text{ cm}
Reconstruction of a chicken wing

- $10^8$ source-detector pairs
- $10^3$ sources and $10^5$ detectors
- 2.6 mm slice separation
- 15 cm x 15 cm FOV
CONCLUSIONS

• We can reconstruct images from large experimental data sets (currently $\sim 10^8$ data points)
• Theory and experiment are in agreement at this stage
• Although it is difficult to quantify, image quality seems to be better than in other optical tomography experiments with similar parameters
Three known factors that impact image quality in our experiments:

1) Noise
2) Mechanical design and precision
3) Number of sources

Solutions:

1) Higher laser power, overexposing the tails of transmission function (but not enough is known about the nature of noise at this time …)
2) Better mechanical precision
3) Using a faster CCD camera (video-rate) will allow us to increase the number of sources by about the factor of 100.
Transmission Through a Slab: Experimental Data vs Theoretical Fit

![Graph showing transmission data and theoretical fit]

- **Experimental data**
- **Theoretical fit**

- $k = 0.44 \text{ 1/cm}$
- $l = 3\text{mm}$

**CCD Pixel Number** [1 pix = 0.65mm]
Transmission Through a Slab: Experimental Data vs Theoretical Fit (LIN – LOG Scale)
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