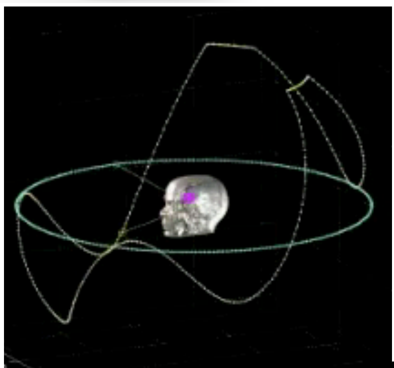
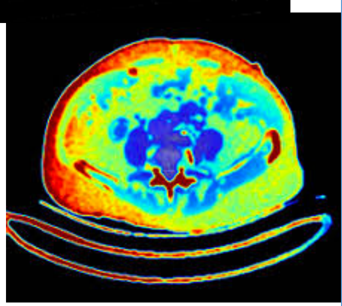


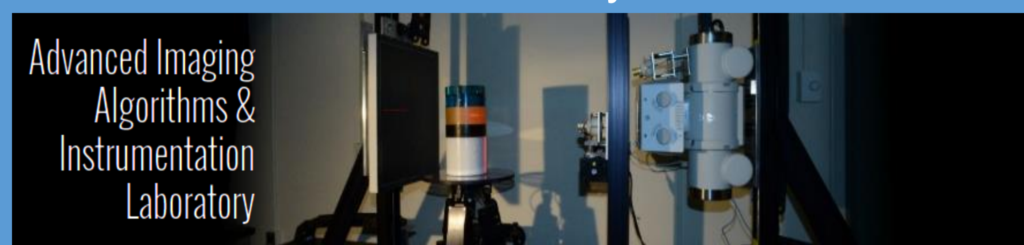


Dynamic x-ray beam positioning for low-dose CT

Computer Integrated Surgery II Seminar Presentation

William Shyr

Mentor: J. Web Stayman Ph.D.



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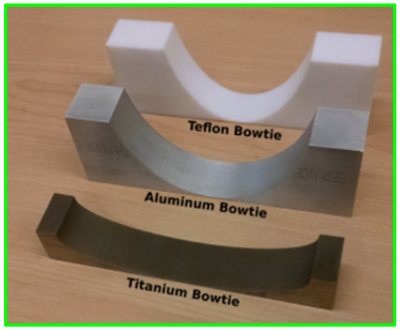
Johns Hopkins Biomedical Engineering

Johns Hopkins Medicine

Project Overview

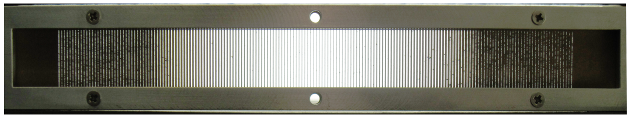
- Patient often miscentered within bore of a CT system
- Increased dose and loss in image quality
- Fluence field modulation strategies



Bowtie filters

Goal

To achieve dynamic x-ray beam positioning in low-dose CT acquisitions and quantitative performance assessment for arbitrary patient positioning in emergency medicine applications


Multiple aperture device (MAD)

Toth et. al., Med. Phys., 2007

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Paper Selection

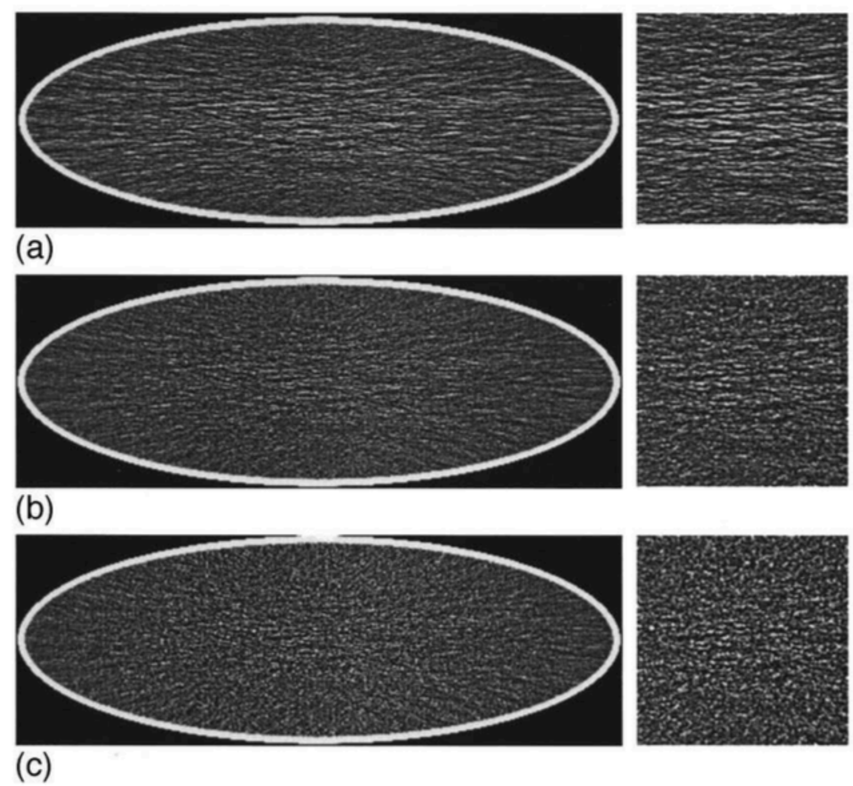
Gies, M., Kalender, W. A., Wolf, H., Suess, C. and Madsen, M. T. (1999), Dose reduction in CT by anatomically adapted tube current modulation. I. Simulation studies. Med. Phys., 26: 2235–2247. doi:10.1118/1.598779.

- Describes techniques for dose reduction
- Methods for modeling and measuring dose and noise

Introduction

Goal
Show that attenuation-based current modulation system can in fact yield significant dose reduction without loss of image quality

Dose reduction methods
- Lowering tube current
- Adapt tube current to x-ray attenuation with projection angle
- Sinusoidal modulation



Introduction

Attenuation

$$A = e^{\mu \cdot L}$$

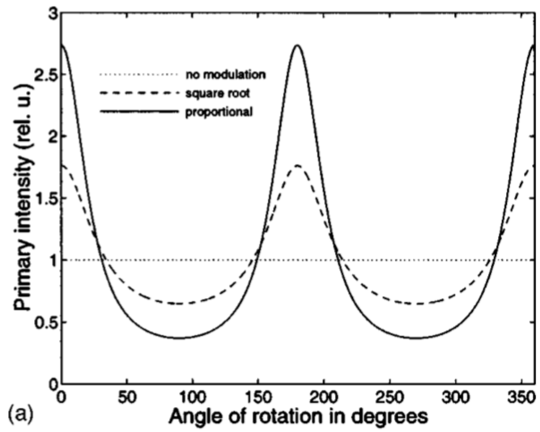
Control parameter α

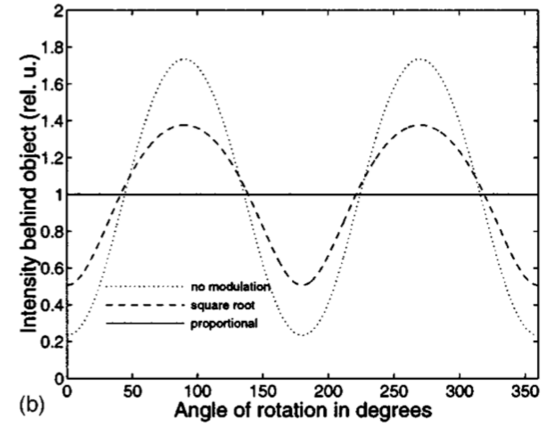
$$A^{\alpha} = e^{\alpha \cdot \mu L}$$

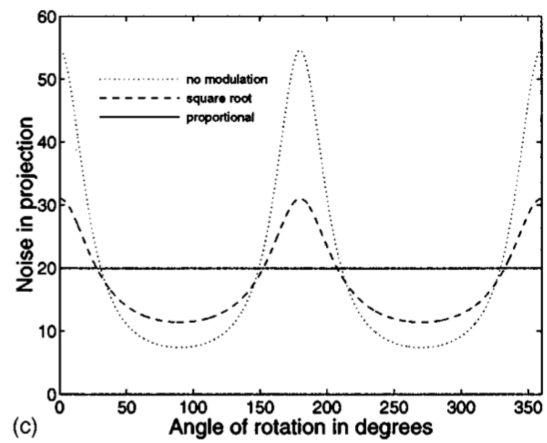
Pixel noise variance

$$\sigma^2 = \sum_{i=1}^{N_P} \frac{1}{N_i}$$

number of quanta in view i passed through object







Can be shown that $\alpha = 0.5$ optimal

Pixel noise variance

$$A_i = \frac{N_{0i}}{N_i}$$

$$\sigma_P^2 = \sum_{i=1}^{N_P} \sigma_i^2 = \sum_{i=1}^{N_P} \frac{1}{N_i} = \sum_{i=1}^{N_P} \frac{A_i}{N_{0i}}$$

A_i: Attenuation in view i

N_i: number of quanta in view i passed through object

N_{0i}: number of emitted quanta for the central ray in view i

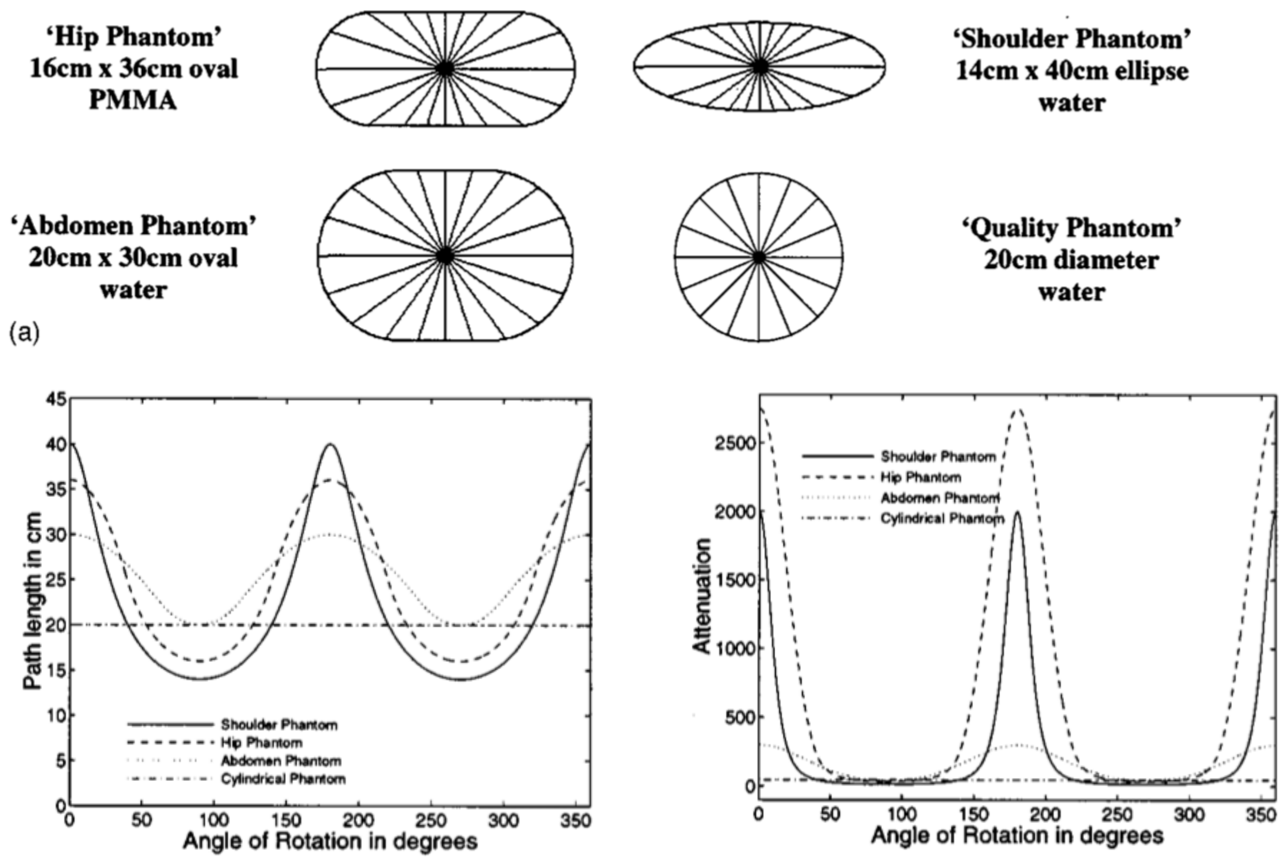
Introduction

Pixel noise variance with control parameter α

$$\sigma_P^2 = \frac{1}{N_0}\left(\sum_{i=1}^{N_P} A_i^{1-\alpha}\right)\left(\sum_{i=1}^{N_P} A_i^{\alpha}\right)$$

- Total number of quanta per scan limited
- Invest in high-attenuation projections lead to high noise for low-attenuation projections
- Noise more homogeneous but higher noise

Methods


'Hip Phantom'
16cm x 36cm oval
PMMA
'Shoulder Phantom'
14cm x 40cm ellipse
water
'Abdomen Phantom'
20cm x 30cm oval
water
'Quality Phantom'
20cm diameter
water
(a)
Path length in cm
Angle of Rotation in degrees
Shoulder Phantom
Hip Phantom
Abdomen Phantom
Cylindrical Phantom
Attenuation
Angle of Rotation in degrees
Shoulder Phantom
Hip Phantom
Abdomen Phantom
Cylindrical Phantom

Method

Simulations

- Constant attenuation coefficient μ
- 120 kVp
- Measure nose reduction as the amount of total scan dose that could be reduced without losing image quality

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Methods

1. Compute attenuation-weighted path length

$$\mu \cdot L(\phi)$$

2. Compute attenuation of central ray

$$A(\phi) = e^{\mu \cdot L(\phi)}$$

3. Compute current modulation function

$$N_0(\phi_i) = N_{0i} \cdot w(\phi)$$

- $w(\phi) = A_{min} + \frac{A_{max} - A_{min}}{2}(1 + \cos 2\phi)$
- $w(\phi) = A(\phi)^{\alpha}$

4. Compute pixel noise for modulation function

$$\sigma = \frac{1}{N_0}\sqrt{\sum_i \sigma_M^2(\phi_i)}$$

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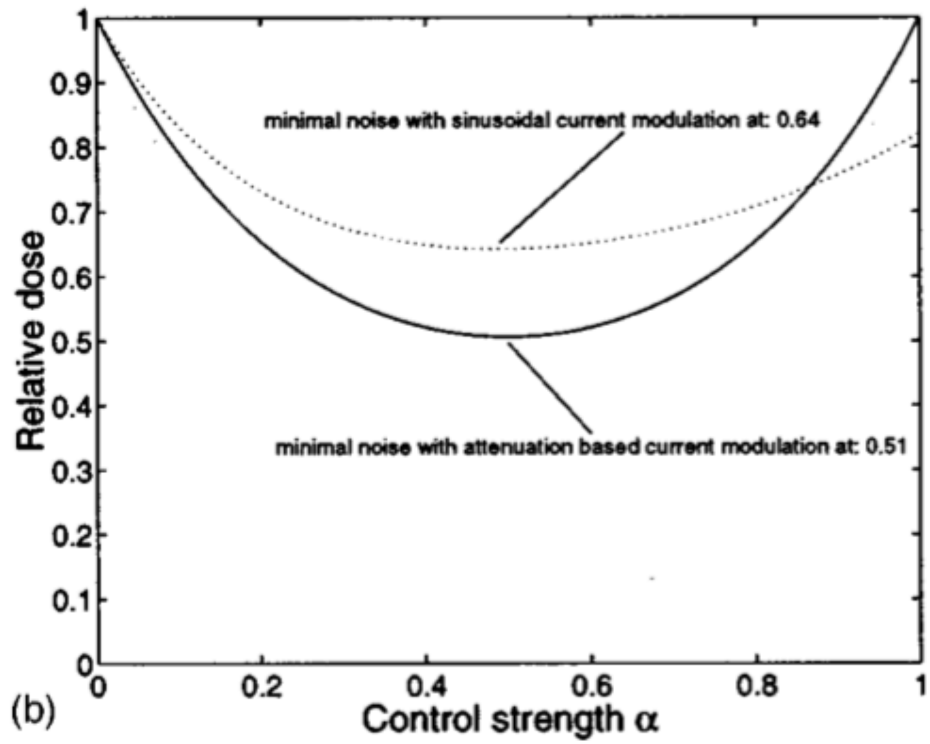
Results: Noise Reduction

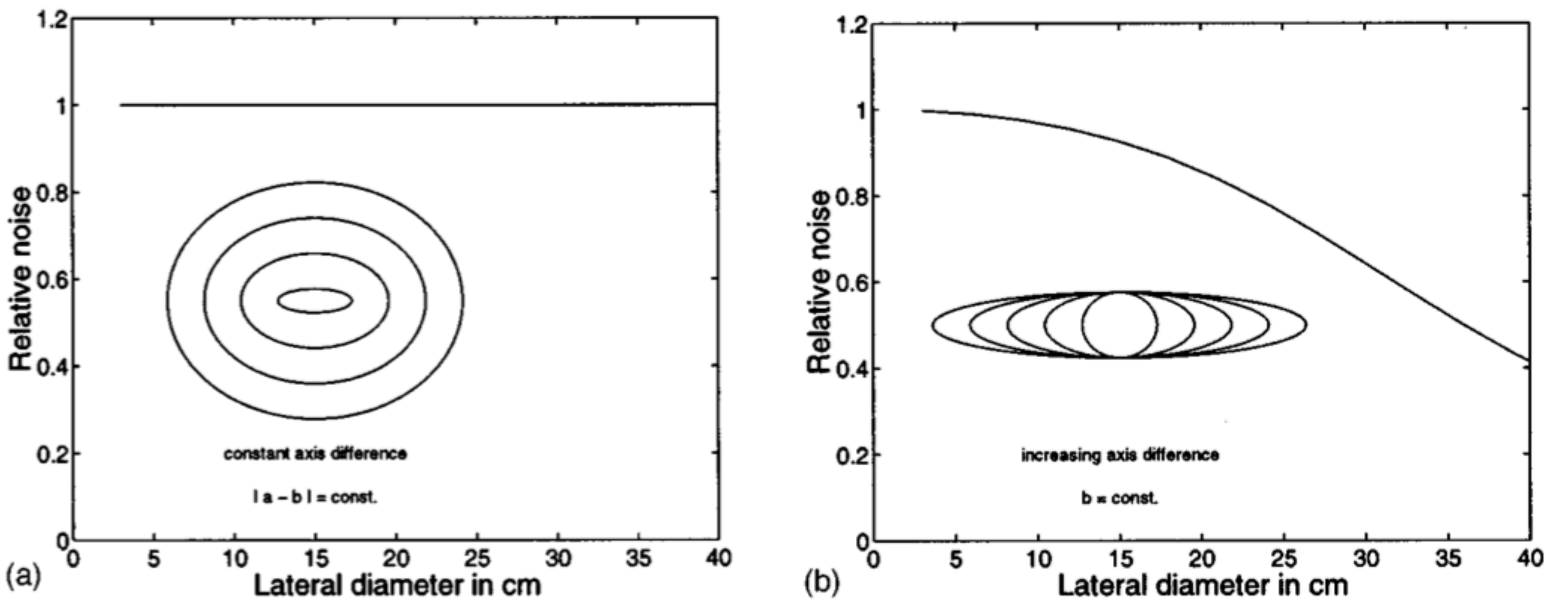
Pixel noise variance with control parameter α

$$\sigma_P^2 = \frac{1}{N_0}\left(\sum_{i=1}^{N_P} A_i^{1-\alpha}\right)\left(\sum_{i=1}^{N_P} A_i^{\alpha}\right)$$



(b)

Results: Noise Reduction

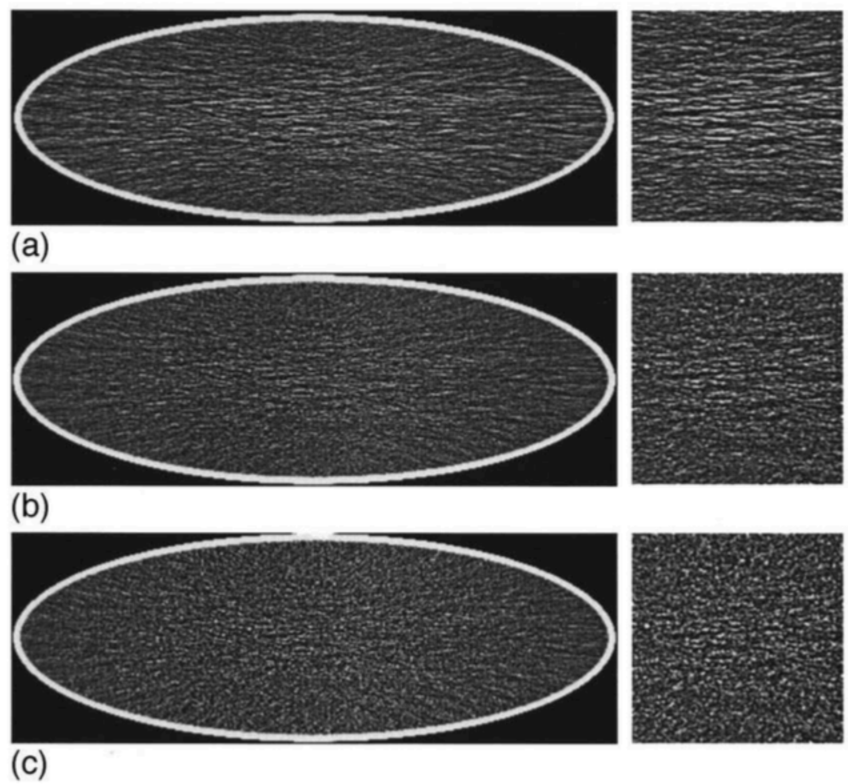


Potential for noise reduction depends on object shape

$$H = \frac{A_{max}}{A_{min}} = \frac{e^{\mu d_{min}}}{e^{\mu d_{max}}} = e^{\mu(d_{max} - d_{min})}$$

Results: Noise Structure

- Pixel noise highest with streaky structure
  - $\alpha = 0$
  - SD = 16.3 HU
- Lowest noise
  - $\alpha = 0.5$
  - SD = 11.1 HU
- Pixel noise becomes more isotropic as α increases
  - $\alpha = 1$
  - SD = 15.5 HU



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Assessment

Pros

- Detailed discussion of noise and dose calculations
- Developed a framework for dose and noise assessment for different objects

Cons

- Only focused on central ray
- Seems to suggest that flat fluence is not the best way to minimize noise
- Results obtained through simulations

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Relevance & Takeaways

- Detailed discussion of noise and dose measurements
- Optimizing fluence profile to minimize noise and dose