Correction and Preprocessing Methods

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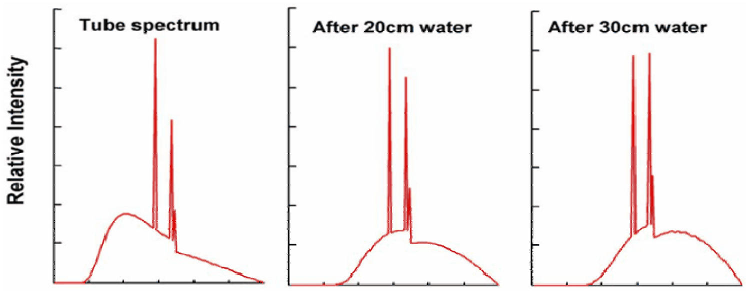
1. Beam hardening

1.1. The phenomena



Photon ratio by monochromatic beam

$$N_d = N_{in} \exp\left[-\int_{ray} \mu(x,y)ds\right]$$

$$\Rightarrow \int_{ray} \mu(x,y)ds = \ln\frac{N_{in}}{N_d}$$

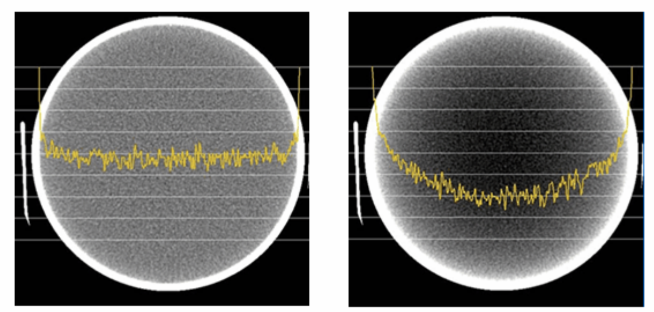
for homogenous medium $\Rightarrow \mu l = \ln\frac{N_{in}}{N_d}$

Photon ratio by polychromatic beam

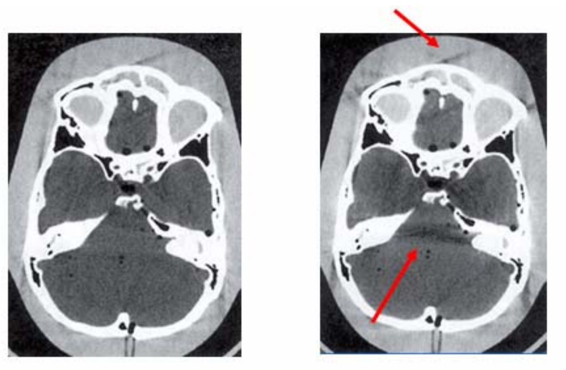
$$N_d = \int S_{in}(E)\exp\left[-\int_{ray} \mu(x,y,E)ds\right]dE \qquad (1)$$

1.2. Beam hardening artefact

- cupping



- streaks



1.3. Correction schemes

Preprocessing

- Assumption for homogeneous medium
- Correction of projection data

Postprocessing

Iterative scheme:

- first: preprocessing step
- second: threshold to identify hard structures
- third: forward-project the contribution of the hard structures into projection data

<u>Dual-energy</u>

Substitute $\mu(x,y,E) = a_1(x,y)g(E) + a_2(x,y)f_{KN}(E)$ in (1)

$$\Rightarrow N_d = \int S_{in}(E)\exp[-(A_1 g(E) + A_2 f_{KN}(E))]dE$$

$$\text{where} \quad A_i = \int_{ray} a_i(x,y)ds, \quad \text{for } i = 1,2 \qquad (2)$$

Two scans with different voltage (different energy curves)

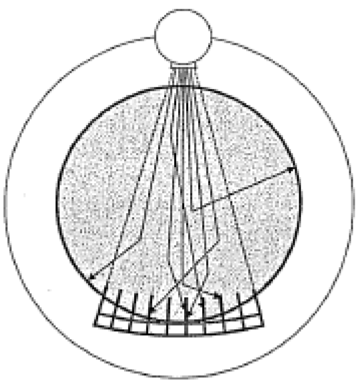
$$I_1(A_1, A_2) = \int S_1(E)\exp[-(A_1 g(E) + A_2 f_{KN}(E))]dE$$

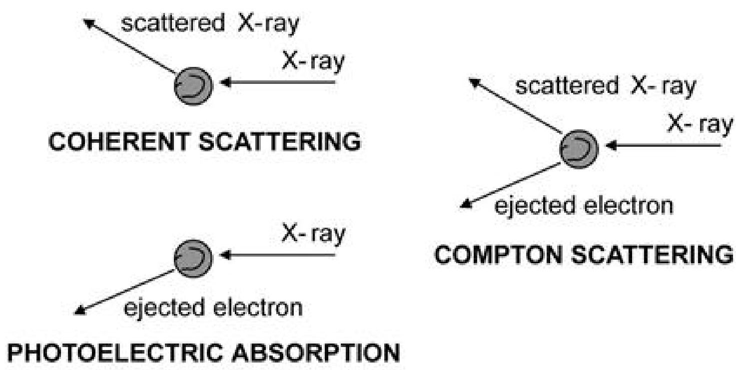
$$I_2(A_1, A_2) = \int S_2(E)\exp[-(A_1 g(E) + A_2 f_{KN}(E))]dE$$

Reconstruct $a_1(x,y)$ and $a_2(x,y)$ $\Rightarrow$ now $\mu(x,y,E)$ can be reconstructed for any energy

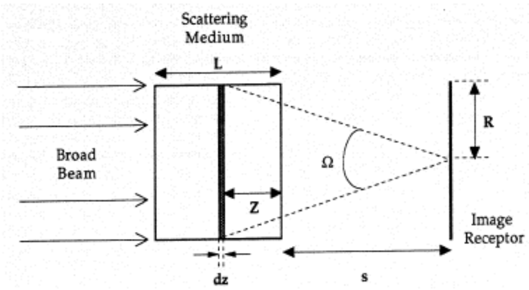
2. Scattered radiation

Scattered radiation is a radiation that is deflected in the scanned medium.





2.1. Scatter-to-Primary Ratio (SPR)



Broad beam model estimation for SPR

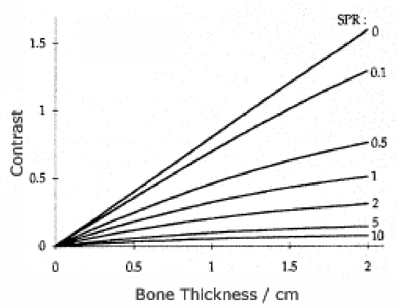
$$SPR = 2\mu_{st}^2 \beta L\left(L + R - \sqrt{L^2 + R^2}\right)\left(1 - \frac{s}{\sqrt{R^2 + s^2}}\right)$$

μ_{st} - scattering attenuation coefficient

β - fraction of scattered photons which are scattered forward

2.2. Scatter artefacts

<u>Loss of contrast</u>



Contrast without scatter: $C = (\mu_b - \mu)t_b$ - linearly depends on material thickness

Contrast with scatter: $C = \ln\dfrac{1 + SPR}{e^{-(\mu_b - \mu)} + SPR}$ - no linear dependence

Loss of sharpness

Transmitted radiation:

$I_t = I_p + I_{sr}$, where $I_{sr} = SPR \cdot I_p ** h_{sr}$

h_{sr} - blurring kernel due to scattered radiation

$**$ - 2D convolution[1]

Detected radiation:

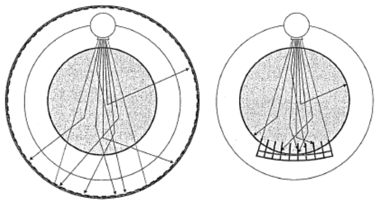
$$I_d = (1-\rho)I_t + \rho I_t ** h_{vg} \Rightarrow$$

$$I_d = (1-\rho)(I_p + SPR \cdot I_p ** h_{sr}) + \rho(I_p + SPR \cdot I_p ** h_{sr}) ** h_{vg}$$

h_{vg} - blurring kernel due to veiling glare

ρ - fraction of veiling

2.3. Scatter Reduction Approaches



- Anti-scatter grid
- Air gaps
- Beam collimation

2.4. Scatter Measurement

- Opaque discs techniques
- Aperture techniques
- Hybrid techniques

2.5. Scatter Correction Schemes

Convolution filtering

Filter the smooth scatter signal from the image

$$I_d = I_p + I_s = I_p + SPR \cdot I_p ** h_s$$

$$\Rightarrow I_p = I_d - SPR \cdot I_p ** h_s$$

Use I_d as an estimation for I_p, W- ratio of scatter signal to the total signal

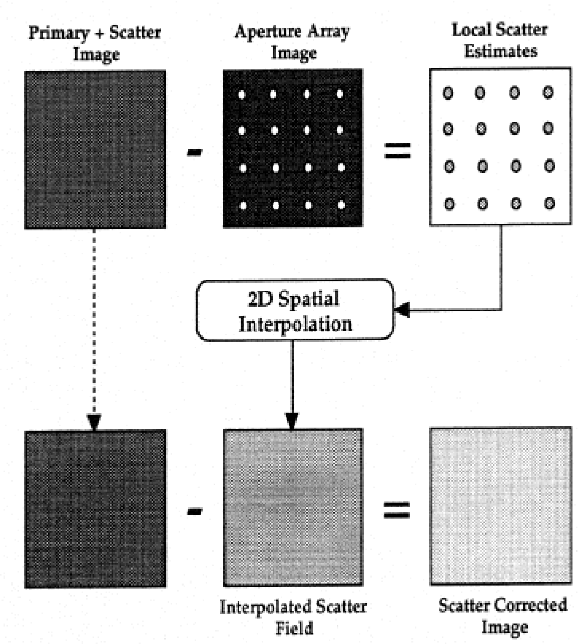
$$I_p = I_d - \underbrace{W(I_d ** h_s)}$$

Low-pass filtered version of the detected signal. Has to be filtered out

[1] 2D convolution - $(g ** h)(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(u,v)h(x-u, y-v)dudv$

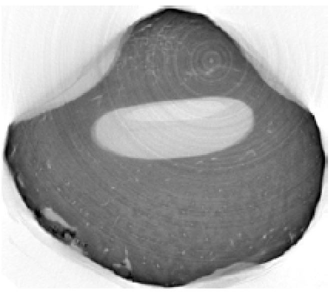
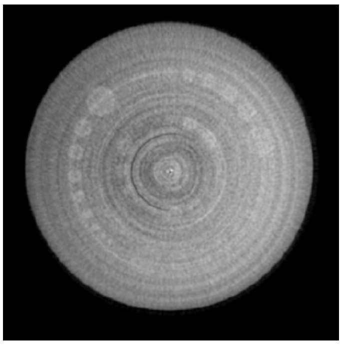
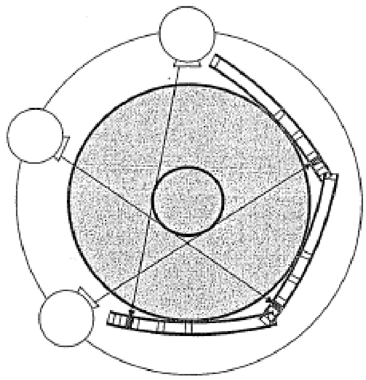
Scatter sampling schemes

- Estimate scatter in sample points
    - Opaque disc arrays
    - Aperture arrays
- Interpolate “scatter surface” (it is a smooth one)
    - 2D least squares fitting
    - Filtration with sinc and jinc
    - 2D polynomial fitting
    - 2D bicubic splines
- Subtract the “scatter surface” estimation from the image



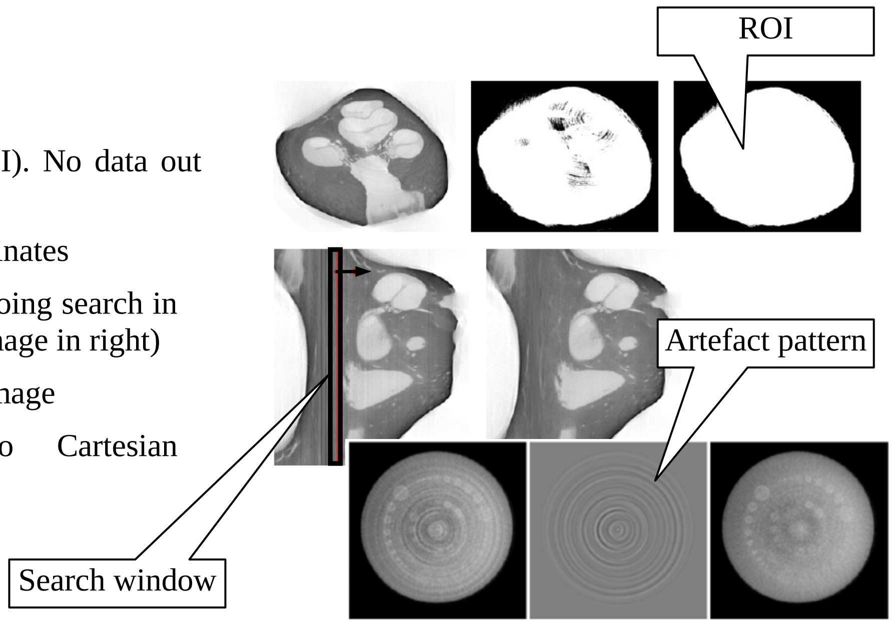
3. Ring artefacts

Artefacts in the reconstructed image due to defect detector units; relevant for thirds generation CT ; only postprocessing correction possible.

3.1. Correction scheme

1. Select Region of Interest (ROI). No data out of it is considered
2. Translate image to polar coordinates
3. Construct artefact pattern by doing search in window (red window on the image in right)
4. Subtract the pattern from the image
5. Translate image back to Cartesian coordinages



4. References

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- K.P.Maher and J.F. Malone, Computerized scatter correction in diagnostic radiology, Contemporary Physics 38, 131-148 (1997).
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