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# Interpolation-Based Reconstructions for Raster-Scanned Backscatter X-ray Radiography

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## Introduction

### Background

- The scanning radiography using a deep-penetrating megavoltage x-ray beam is widely used for screening cargo containers at ports and vehicles at borders, but this imaging technique is weak to discriminate low-Z materials, which are the basis of explosives and drugs
- Backscatter x-ray imaging (BXI), which utilizes image signal with the x-ray photons scattered back from the object, is known to be sensitive to low-Z materials
- The BXI is typically based on the raster scan, which may yield asymmetric, non-uniform sampling pitches along with horizontal and vertical directions; thus, without appropriate consideration for the raster scanning, the resulting images will suffer from geometric distortions

### Objectives

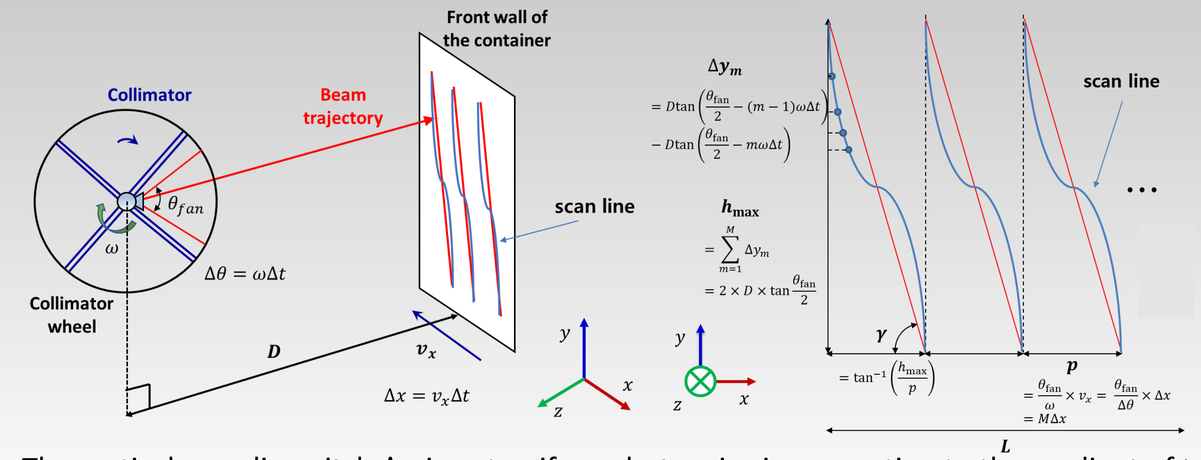
- To formulate the raster-scanning trajectories considering the angular velocity of the collimator wheel and object speed, and to show the geometric distortions in scanned images
- To propose two simple synthetic algorithms of the raster-scan-sampled data, such as the distance-weighted average (WA) and the geometric interpolation (GI)

## Methods

### Beam trajectory

| Symbol | Description |
|---|---|
| $\theta_{\text{fan}}$ [rad] | Fan angle |
| $\omega$ [rad/s] | Angular velocity of collimator |

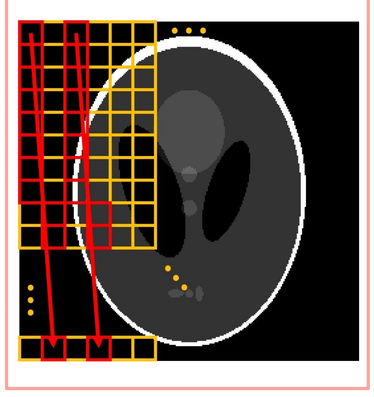
| Symbol | Description |
|---|---|
| $\Delta t$ [sec] | Detector readout time |
| $v_x$ [m/s] | Velocity of vehicle |
| $\Delta x, \Delta y$ [m] | Sampling pitches |



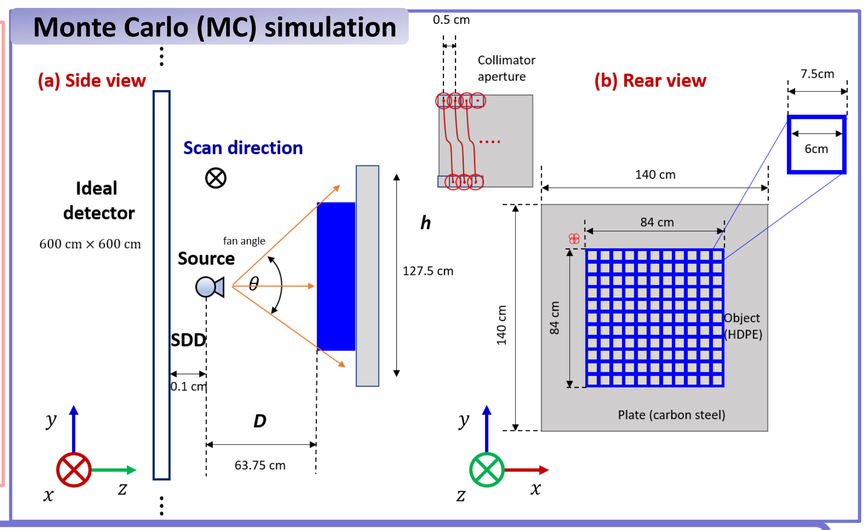

- The vertical sampling pitch $\Delta y$ is not uniform, but varies in proportion to the gradient of $\tan\theta$

### Computer simulations

#### Numerical simulation



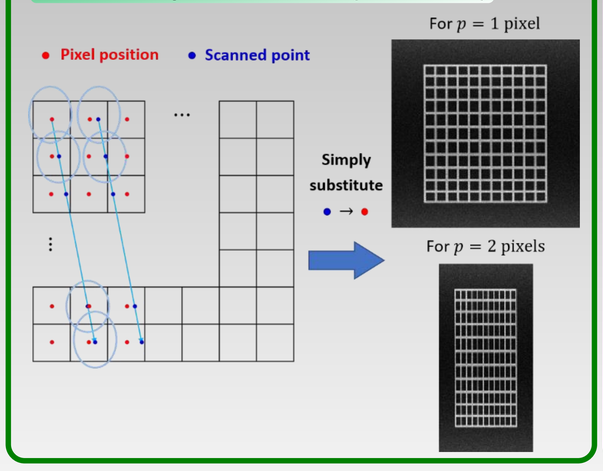
#### Monte Carlo (MC) simulation



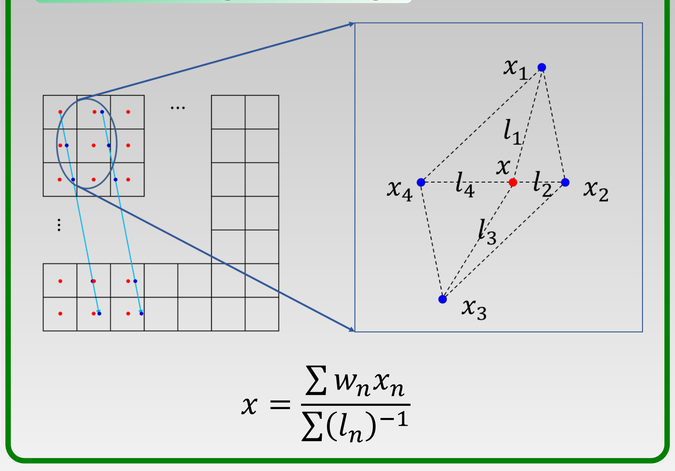

- Geometric distortion in the BXI is evaluated for a mesh phantom consisting of HDPE
- Raster-scan sampling is performed using the commercial MC code (MCNP version 5)
- BXI is performed for the Shepp-Logan phantom using MATLAB® 2020a
- Raster-scan sampling is performed using the Siddon's ray-tracing algorithm

### Synthesis methods

#### Shift-and-place method (reference)

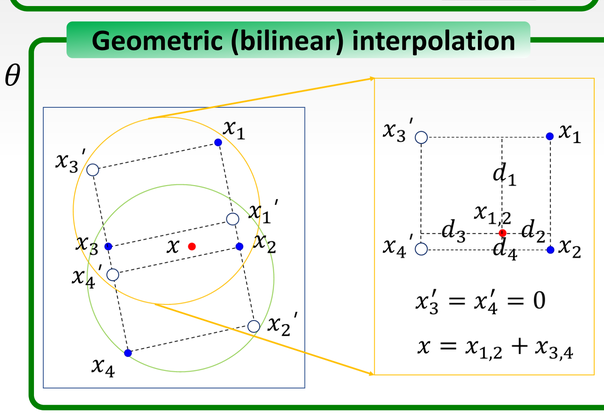



#### Distance-weighted average




$$x = \frac{\sum w_n x_n}{\sum (l_n)^{-1}}$$

#### Geometric (bilinear) interpolation




$$w_1 = \frac{d_3 d_4}{(d_1 + d_4)(d_2 + d_3)} \quad w_2 = \frac{d_1 d_3}{(d_1 + d_4)(d_2 + d_3)}$$
$$w_3 = \frac{d_2 d_4}{(d_1 + d_4)(d_2 + d_3)} \quad w_2 = \frac{d_1 d_2}{(d_1 + d_4)(d_2 + d_3)}$$
$$x = \sum w_n x_n$$

### Performance evaluation

- The conventional shift-and-place (SAP) and the proposed WA GI methods are evaluated by measuring the SSIM and the NMI between the synthetic image $\mathbf{x}$ and the original image $\mathbf{y}$

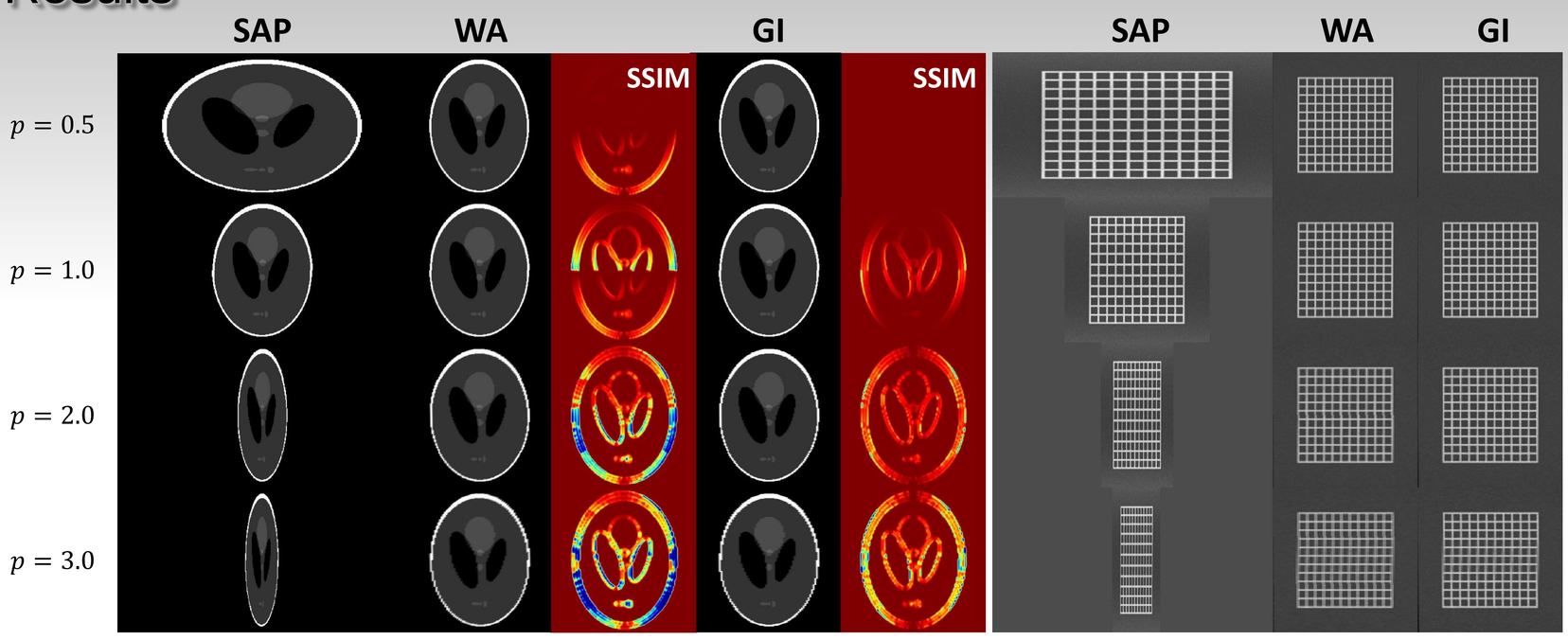
**Structural similarity index (SSIM)**

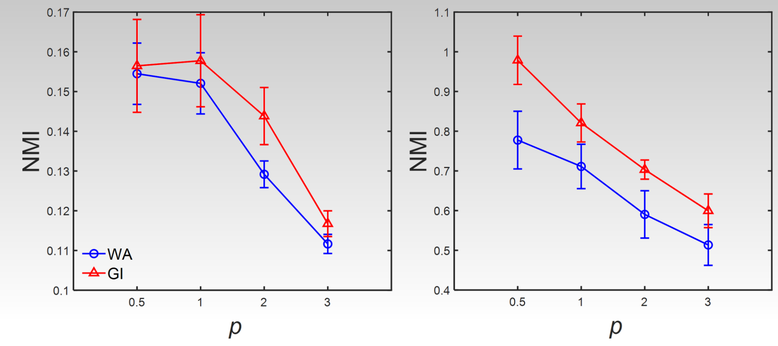
$$\text{SSIM}(\mathbf{x}, \mathbf{y}) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

**Normalized mutual information (NMI)**

$$H(\mathbf{x}) = -\sum_{n=1}^{N} p(x_n)\log[p(x_n)]$$
$$H(\mathbf{x}, \mathbf{y}) = -\sum_{n=1}^{n}\sum_{m=1}^{M} p(x_n, y_m)\log[p(x_n, y_m)]$$
$$I(\mathbf{x}, \mathbf{y}) = H(\mathbf{x}) + H(\mathbf{y}) - H(\mathbf{x}, \mathbf{y})$$
$$\text{NMI}_{\text{joint}} = \frac{I(\mathbf{x}, \mathbf{y})}{H(\mathbf{x}, \mathbf{y})}$$

## Results




- The conventional SAP method results in large distortion for the scan-line period $p \neq 1$
- The GI method shows the best performance among the three synthesis methods
- Since the low structural complexity provides a better approximation, the Shepp-Logan phantom is more effectively restored than the mesh one
- Nevertheless, a large $p$ can lead to significant distortion

## Conclusion

- The conventional raster scanning for BXI can result in large distortions in synthetic images, depending on the mismatch between the $\omega$ and $v_x$
- The proposed synthesis methods restored reasonably the original image with some distortions around the relatively fine-sampling regions, even under the extreme raster-scanning conditions; thus they may also be used to accelerate the raster-scan procedure
- Our next study will include more quantitative evaluations of the proposed methods for a wide range of scan parameters, including phantom design

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