Digital X-ray Tomosynthesis of Very Thin-Slab Objects

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Background

- In the manufacturing process, the defects detection in thin-slab objects is regarded as an indispensable procedure and the digital tomosynthesis (DTS) method can be appropriately used for this application
- The DTS method needs a wide scan angular range and a small step angle for less out-of-plane artifact and less noise in the reconstruction image [*Timothy et al. SPIE. (2007)*]
- The DTS method in a step-and-shoot fashion can suffer from the trade-off between the image quality and the inspection time

Objective

- Augmenting a few number of projection images by view-interpolation (VI) method
  1. To reduce the time for the inspection of thin-slab objects
  2. To gain higher image quality than the conventional reconstruction image

View-interpolation method

- For the interpolation, two projection images are used
- However, when the arbitrary voxels of object are irradiated, they are positioned on the detector plane depending on the projection angle
- For this reason, the re-position process is required for the interpolation
  - Re-position process
    - Coordinates conversion relation

      $\hat{u} = \hat{x}\sin\alpha + \hat{y}\cos\alpha, \hat{v} = \hat{z}$
    - Position of a target voxel on the detector plane

$$u_0 = \frac{d(x_0 \sin\alpha + y_0 \cos\alpha)}{r - x_0\cos\alpha + y_0 \sin\alpha}$$

$$v_0 = \frac{dz_0}{r - x_0\cos\alpha + y_0 \sin\alpha}$$

    - Correlation of the coordinates at $\alpha°$ with $\theta°$
      - x_0 can be assumed to zero at thin objects

$$u' = u_0 \frac{m_\theta \cos\theta}{m_\alpha \cos\alpha}, v' = v_0 \frac{m_\theta}{m_\alpha}$$

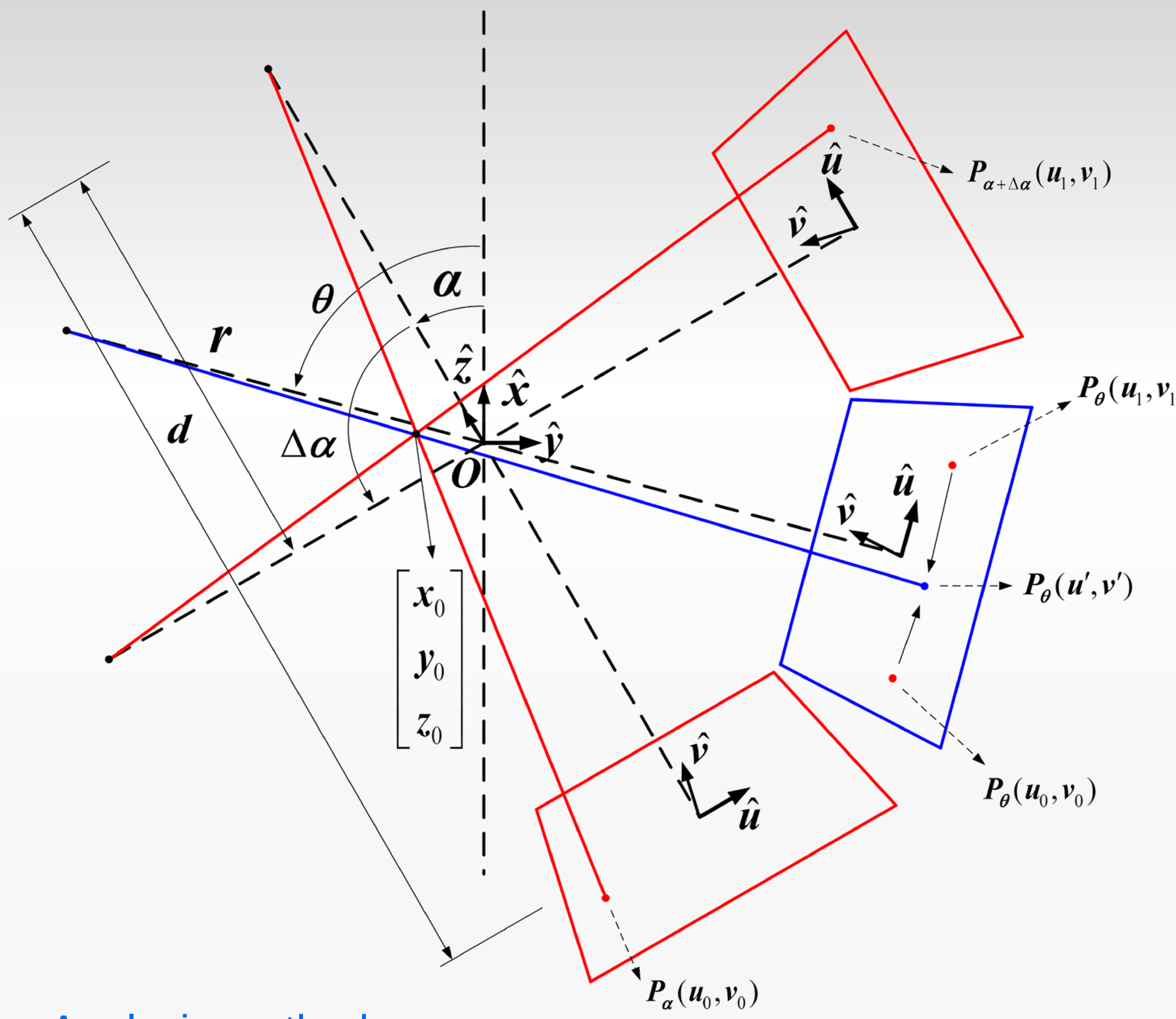
    - Re-positioning operator

$$R_\alpha^\theta\{P_\alpha(u,v)\} = P_\alpha\left(u\frac{m_\theta \cos\theta}{m_\alpha \cos\alpha}, v\frac{m_\theta}{m_\alpha}\right)$$

  - Interpolation process
    - Applying the weighting factor to adjacent images

$$P_\theta(u,v) = w_\theta R_\alpha^\theta\{P_\alpha(u,v)\} + (1-w_\theta)R_{\alpha+\Delta\alpha}^\theta\{P_{\alpha+\Delta\alpha}(u,v)\}$$

- Simulation geometry



- Parameters
  - Coordinates

$\hat{x}, \hat{y}$, and $\hat{z}$	The global coordinates
$\hat{u}$ and $\hat{v}$	The local coordinates
x_0, y_0, and z_0	A target voxel in the global coordinates
u_0 and v_0	The position of a projected target voxel on the detector plane
u' and v'	The position of the re-positioned projected target voxel

  - Single values

α and θ	The projection angles
r	The source to object distance
d	The source to detector distance
m_α	The magnification of a target voxel at $\alpha°$
w_θ	The weighting factor depending on $\theta°$

  - Operators

R_α^θ	The re-positioning operator from the detector plane at $\alpha°$ to $\theta°$
$P_\alpha(u,v)$	A pixel value at the point of (u,v) on the detector plane at $\alpha°$

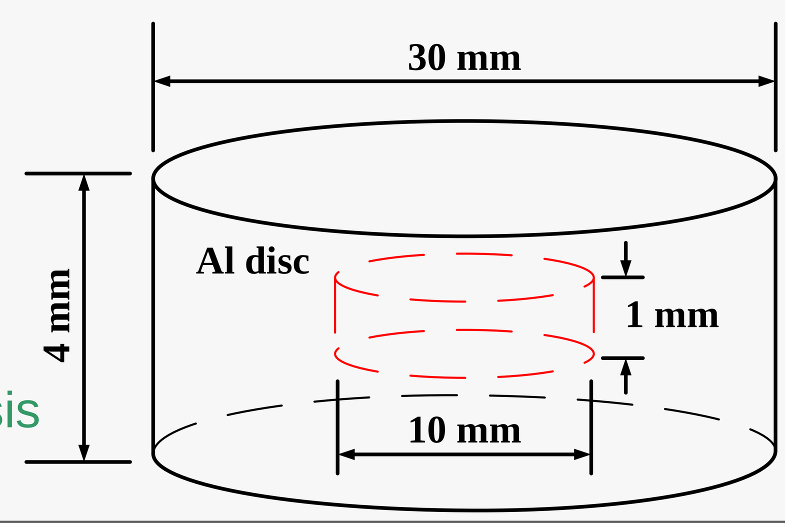
- Analysis method
  - Signal-Difference-to-Noise Ratio (SDNR)
    - Signal performance is measured

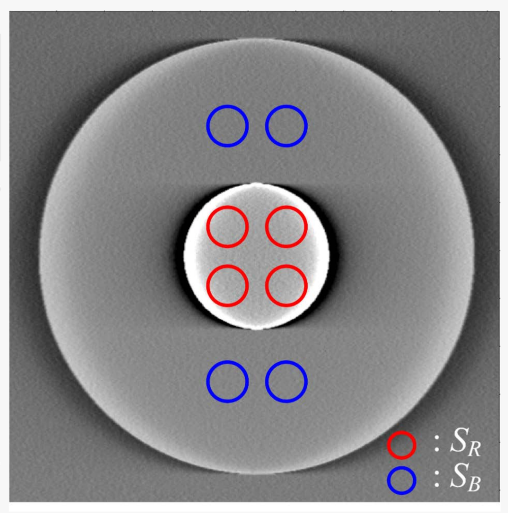
$$\text{SDNR} = \frac{S_R - S_B}{\sigma_B}$$

  - Artifact Spread Function (ASF)
    - Artifact performance is measured

$$\text{ASF} = \frac{S_R(z) - S_B(z)}{S_R(z_0) - S_B(z_0)}$$

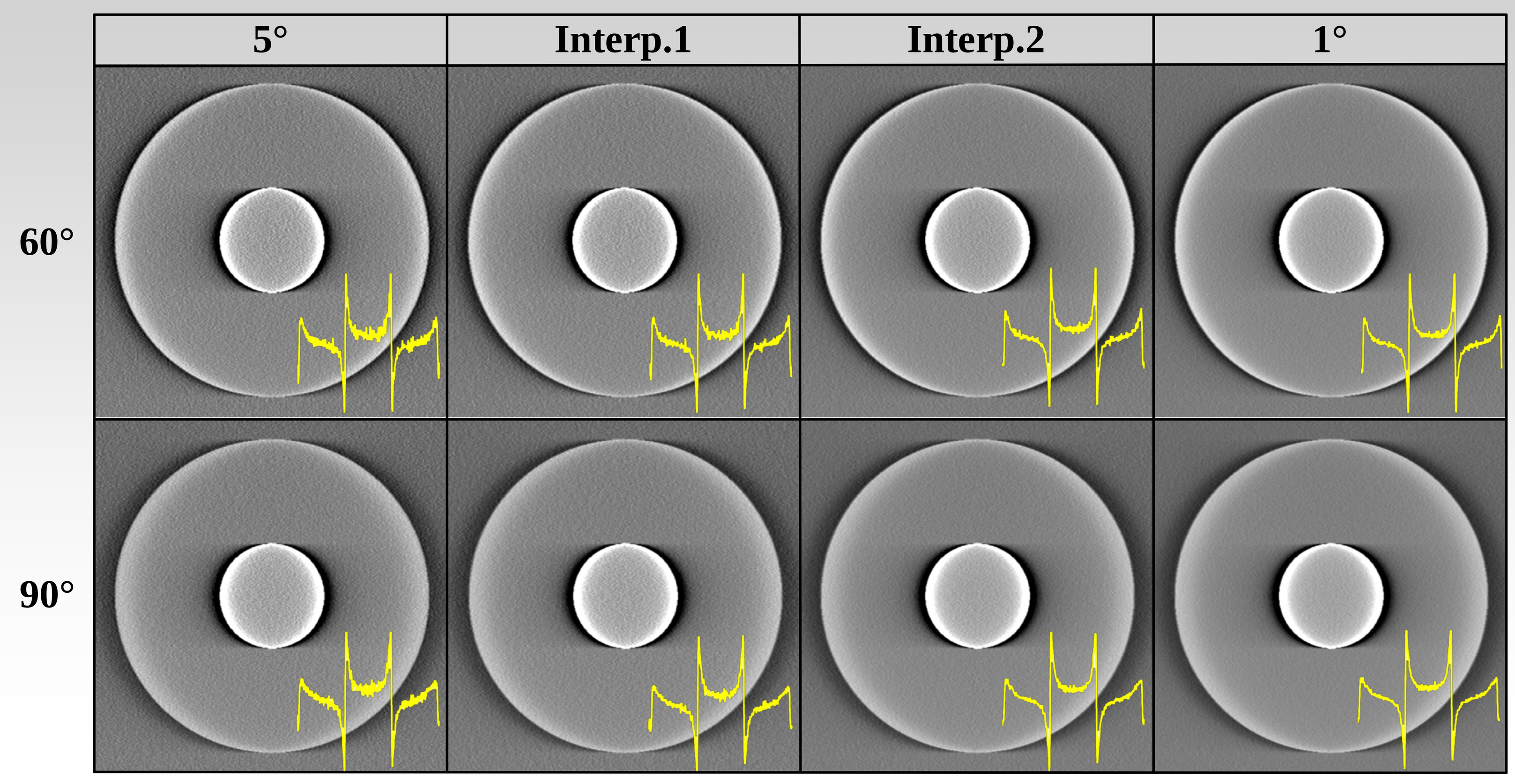
  - Numerical disc phantom for the analysis





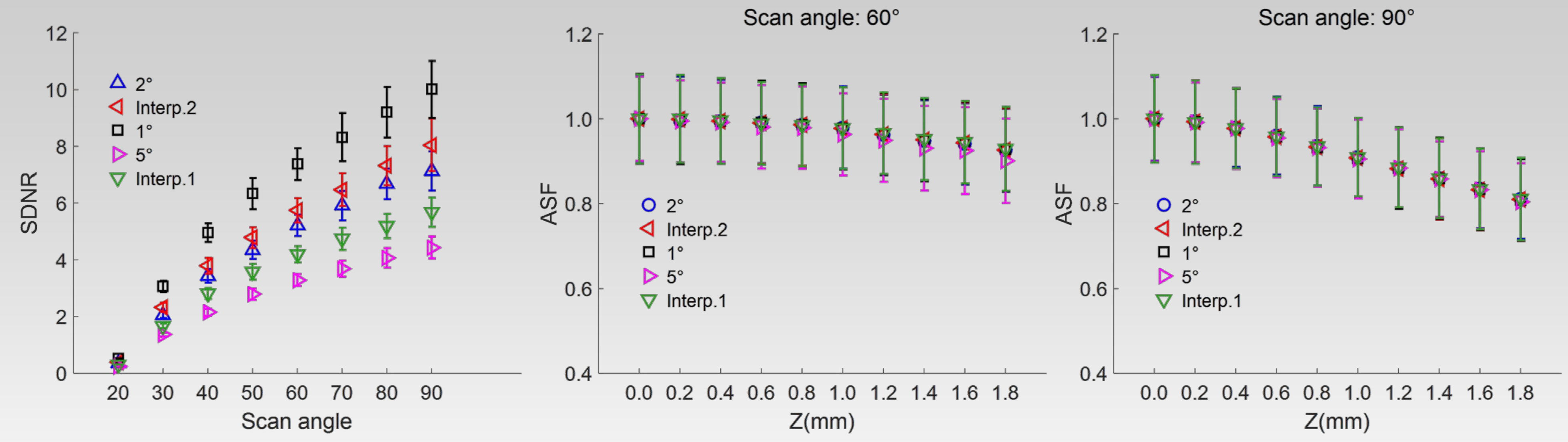
Results

- Reconstructed images and profiles



- Interpolated images from the step angle of 5° to 1° were utilized on the reconstruction images of interp.1 and from that of 2° to 1° those of interp.2
- Profiles of the interpolated reconstruction images contain less noise than those of the reconstruction images without the VI
- The more projection images are used for the interpolation, the less noise is shown on the reconstruction images

- Quantitative performances



- Results of SDNR show that the reconstruction images where the VI process was applied gain averagely 1.3 times higher performance than the conventional reconstruction images in every scan angle except 20°
- ASF graphs indicate that the step angle for the inspection has no influence on the ASF whether the VI method was applied or not

Discussion & conclusion

- The VI method can improve the signal characteristic but not beneficial enough to compare with the reference reconstruction image. Therefore, it is proper to use the VI method in the conditions requiring economy of time
- As scan angle increases, SDNR increases as well. Using this information, we expect that the VI method can be applied to the computed tomography

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