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Digital x-ray tomosynthesis with interpolated projection data for thin slab objects

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Background

- The digital x-ray tomosynthesis (DTS) technique (more generally known as the limited-angle tomography) is well suitable for the defect inspection in thin slab objects such as printed-circuit boards (PCBs)
- For less out-of-plane blur artifact and less noise in the reconstruction images, the DTS requires a wide angular scan range (β) and a small step angle ($\Delta\alpha$) [T. Deller et al., SPIE, 6510, 1L1-1L11 (2007)]
- Accounting for the image quality and the inspection time, therefore, the scanning protocol (e.g. β and $\Delta\alpha$) should be optimized for the reliable use of DTS for the PCB inspection
- It would be desirable if we can provide reconstructed images with an acceptable image quality obtained for a larger β and a smaller $\Delta\alpha$ in a reasonable inspection time, but the smaller $\Delta\alpha$ may restrict the inspection time
- For a given inspection time, the measurement of projection at the small $\Delta\alpha$ is challenging

Objective

- We suggest a $\Delta\alpha$-reduction method that augments the number of projection data by using a projection-interpolation (PI) method for projection images obtained at coarse $\Delta\alpha$
  1. To reduce the scanning time for the inspection of planar objects
  2. To gain better image quality (i.e. less noise) than that reconstructed for the projection images at coarse $\Delta\alpha$

Projection interpolation algorithm

- The PI method assumes that the object to be scanned is rigid and infinitesimally thin
- Projection coordinates for a specific position within the object depend on the rotation angle, α
- For the interpolation of two projection images at α and $\alpha+\Delta\alpha$, two processes are required: coordinates transformation and interpolation process

- Coordinates transformation
  - Relationship between coordinates

$$\hat{u} = \hat{x}\sin\alpha + \hat{y}\cos\alpha, \hat{v} = \hat{z}$$

  - Conversion of object to detector coordinates

$$u_i = \frac{d(x_i\sin\alpha + y_i\cos\alpha)}{r - x_i\cos\alpha + y_i\sin\alpha}$$

$$v_i = \frac{dz_i}{r - x_i\cos\alpha + y_i\sin\alpha}$$

  - Interpolated coordinates
    - x_i can be assumed to zero at thin objects

$$(u_i)_\theta = (u_i)_\alpha\frac{m_\theta\cos\theta}{m_\alpha\cos\alpha}, (v_i)_\theta = (v_i)_\alpha\frac{m_\theta}{m_\alpha}$$

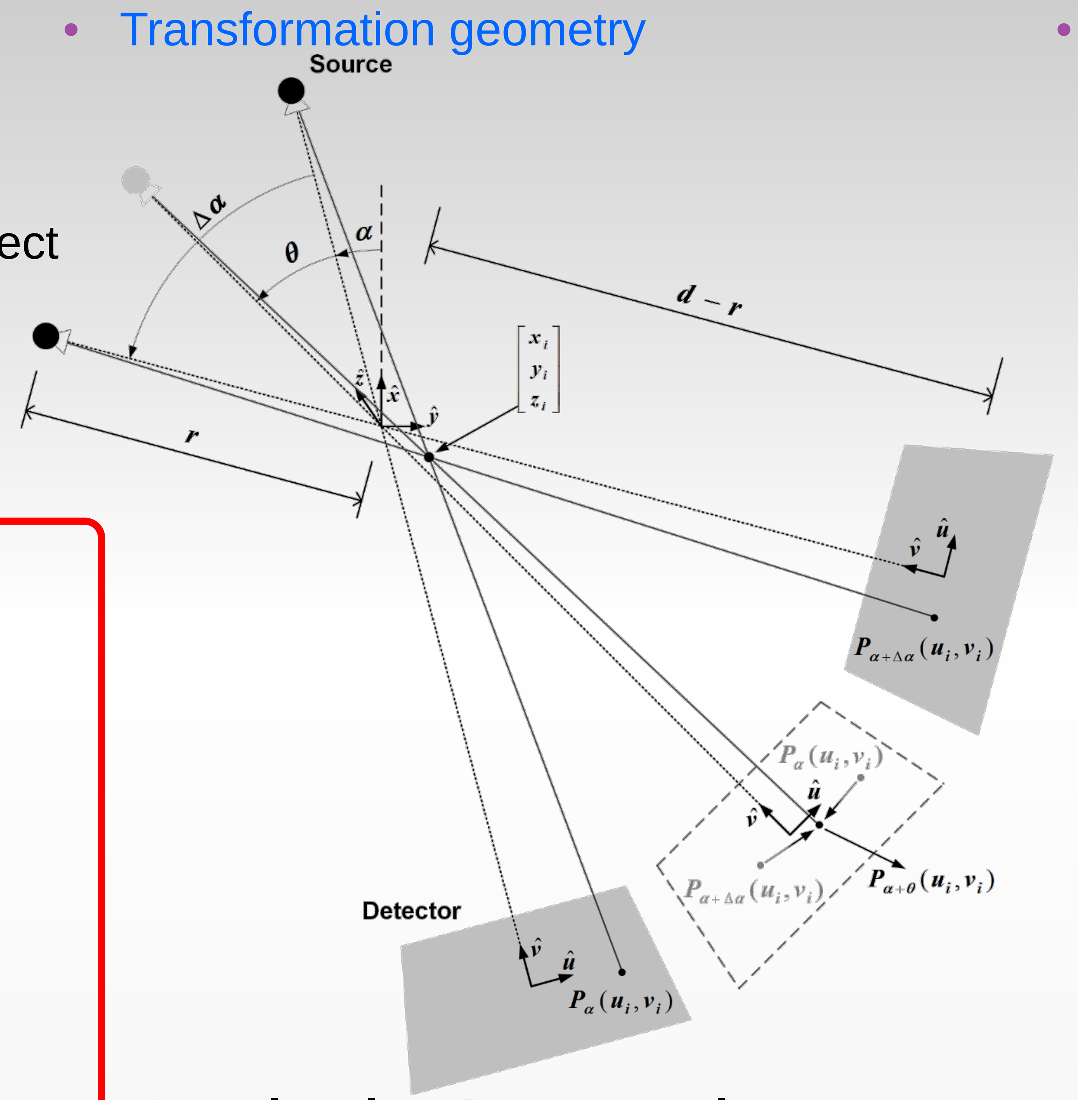
  - Coordinates-transform operator

$$R_\alpha^\theta\{P_\alpha(u_i, v_i)\} = P_\alpha(u_i\frac{m_\theta\cos\theta}{m_\alpha\cos\alpha}, v_i\frac{m_\theta}{m_\alpha})$$

- Interpolation process
  - The weighting factor for the images obtained at α & $\alpha+\Delta\alpha$

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

- Transformation geometry



- Parameters
  - Coordinates
  - Operators

Coordinates		Operators	
$(\hat{x}, \hat{y}, \hat{z})$	Global coordinates	R_α^θ	Coordinates-transform operator from the detector plane at $\alpha°$ to $\theta°$
$(\hat{u}, \hat{v})$	Local coordinates		
(x_i, y_i, z_i)	A target voxel in the global coordinates	$P_\alpha(u_i, v_i)$	A pixel value at the point of (u_i, v_i) on the detector plane at $\alpha°$
(u_i, v_i)	A projected target voxel on the detector plane		

  - Geometric and interpolation parameters

α	Projection angle	d	Source to detector distance
θ	Interpolation angle	m_α	Magnification of a target voxel at $\alpha°$
$\Delta\alpha$	Step angle	w_θ	Weighting factor depending on $\theta°$
r	Source to object distance		

Analysis & experiment

- Signal-difference-to-noise ratio (SDNR)

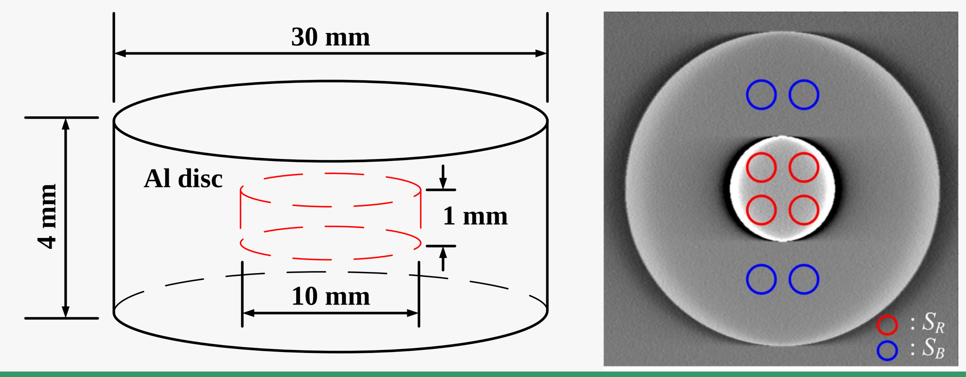
$$\text{SDNR} = \frac{S_R(z_0) - S_B(z_0)}{\sigma_B(z_0)}$$

- Artifact spread function (ASF)

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

[T. Wu et al., Med. Phys., 31, 2636-2647 (2004)]

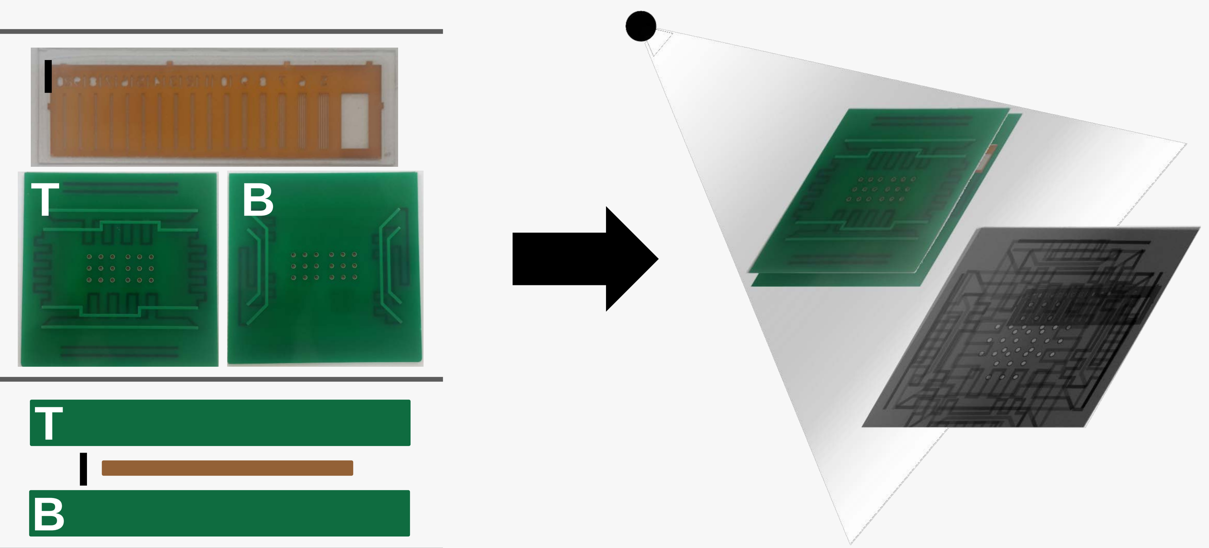
- Numerical disc phantom for analysis



- Phantom for the experiment

Parts

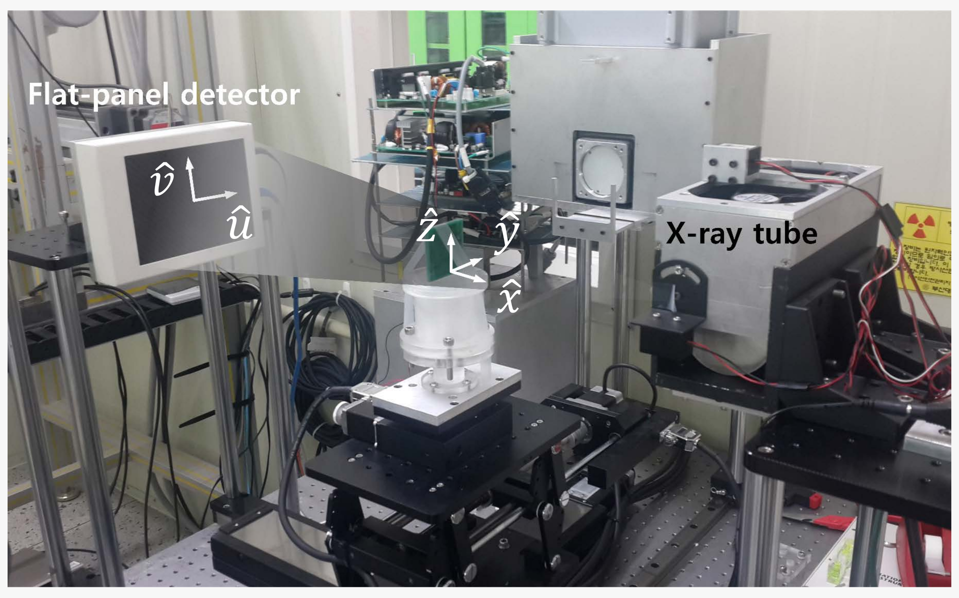
Assy.



- Experimental conditions

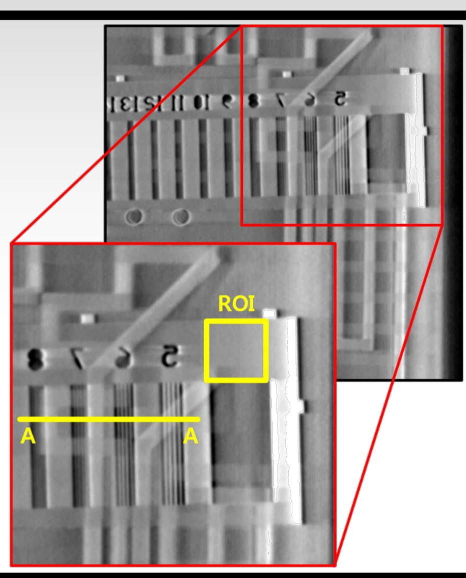
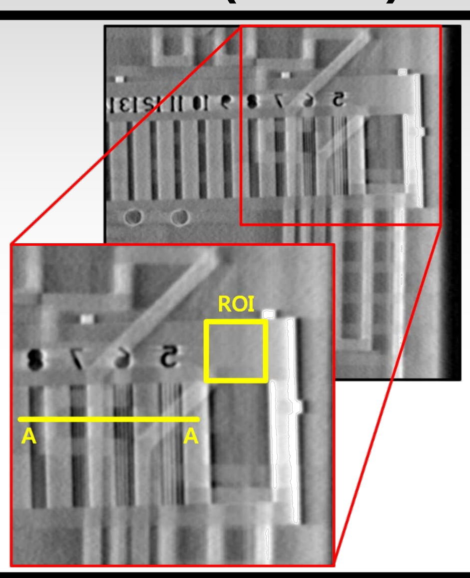
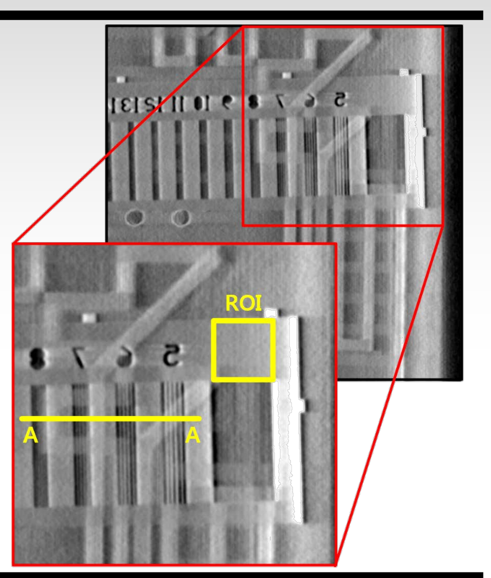
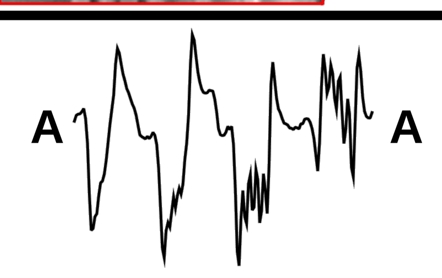
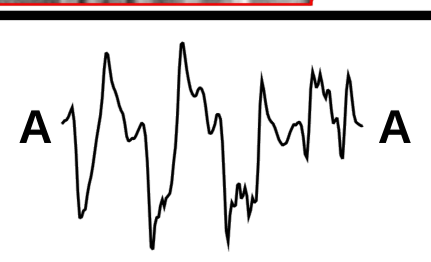
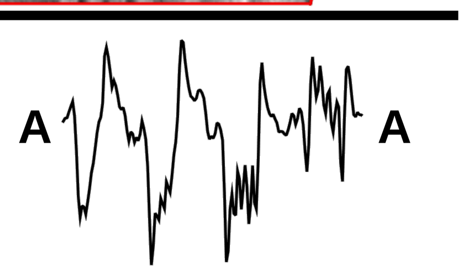
Experimental setup

SDD	SOD	Al-filter
665.86 mm	302.66 mm	2.5 mmAl
kVp	**mA**	**Integration time**
45 kVp	0.9 mA	250 ms
Det. size	**Pixel size**	**Voxel size**
1548 x 1032	0.099 mm	0.045 mm
Recon. size	**Scan angle**	**Step/interp. angle**
512 x 512	120°	5°/1°



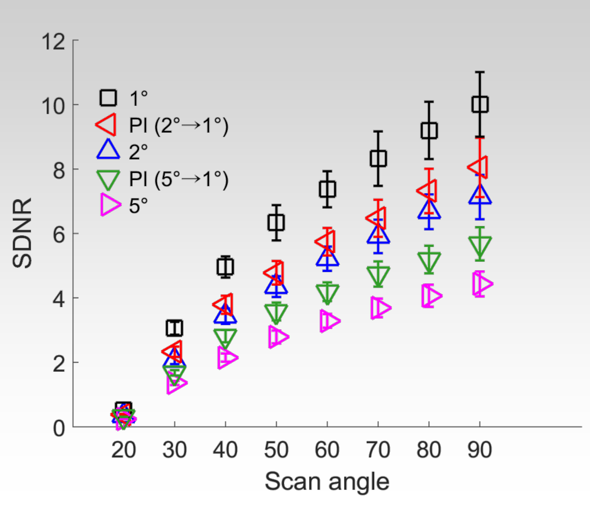
Results

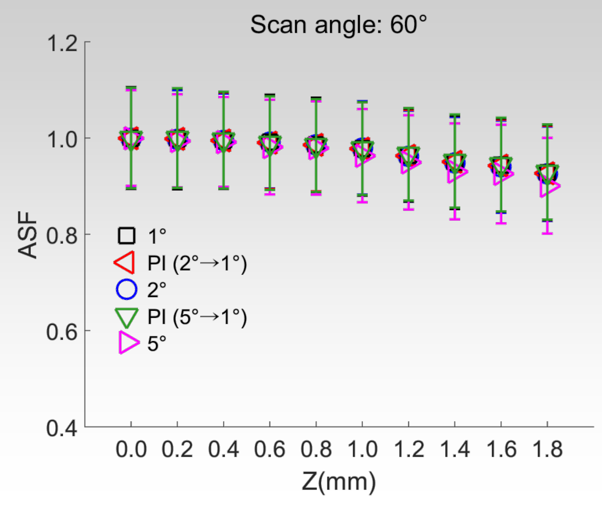
- Experimental results

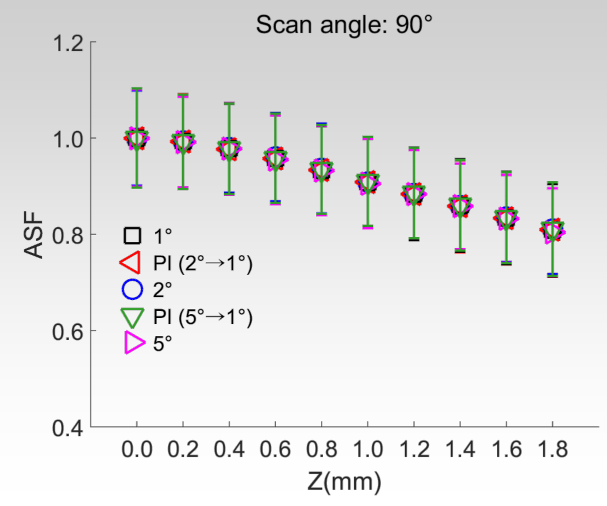
Δα	1°	PI (5°→ 1°)	5°
Image			
Profile			
SNR (ROI)	3.0156	2.5748	2.1718

ROI: Region of interest

- Quantitative performances







Summary

- The results of SDNR have shown that the reconstructed simulation images with the PI process gain, on the average, 1.3 times higher performance than the conventional reconstructed simulation images
- The ASF graphs indicate that the step angle for the inspection has no influence on the ASF whether the PI method is used or not
- The PI method can improve the noise characteristic but may harm the spatial resolution by blurring the reconstruction image. Therefore, it is proper to use the PI technique if the scanning time and noise reduction are the priority of the inspection

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