Comparative study of analytic and iterative digital tomosynthesis reconstructions for thin slab objects

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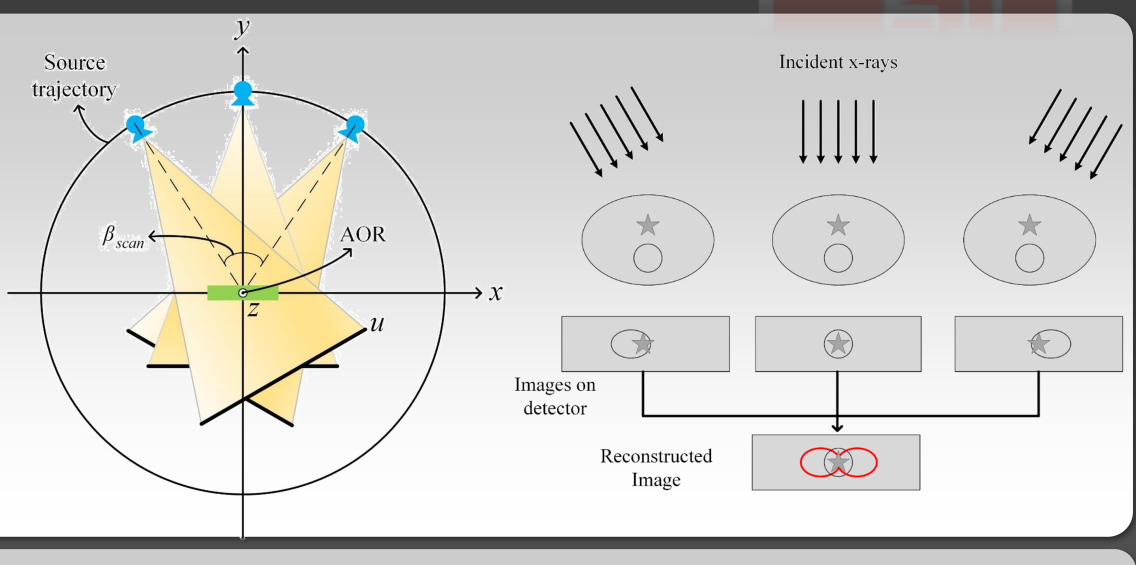
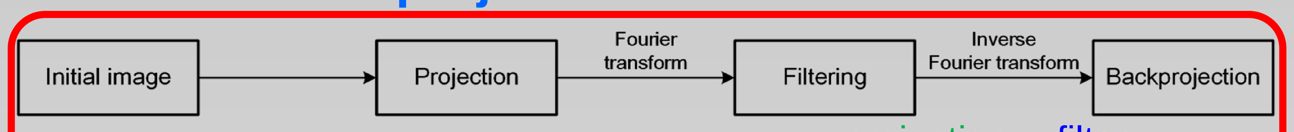
Background and Objectives

- Because the digital x-ray tomosynthesis is known as the image reconstruction technique for a limited-scan angle, it is relevant to acquire tomographic images of thin objects such as printed-circuit boards (PCBs)
- However, out-of-plane blur artifacts can appear in the reconstructed images due to insufficient data sampling
- The filtered backprojection (FBP) algorithm is most widely used to reconstruct images in the digital tomosynthesis, and the simultaneous algebraic reconstruction technique (SART) algorithm can be an alternative
- In this study, we compare the reconstructed images obtained using the FBP and SART algorithms to assess which algorithm is more suitable for the PCB inspection in the limited-angle tomography



Materials and Methods

- **Filtered backprojection**

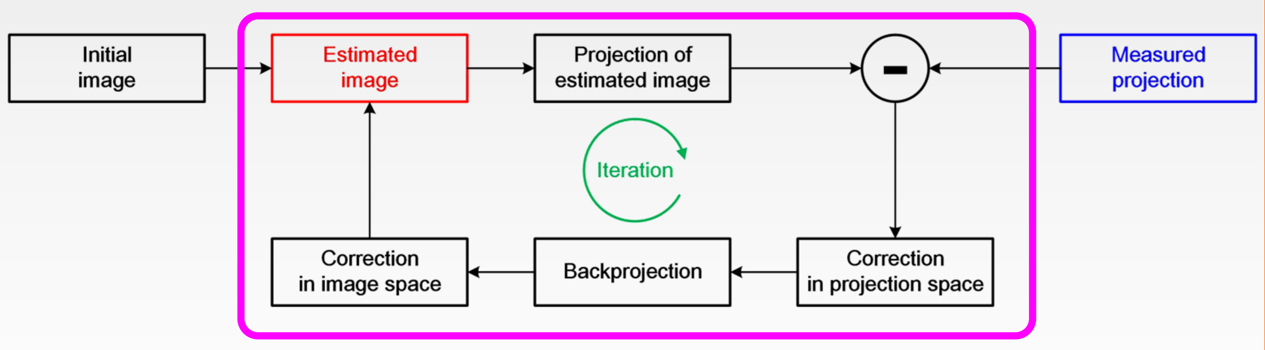


$$f(x,y;z) = \int_{\beta_{min}}^{\beta_{max}} \frac{d_{SD}^2}{(d_{SO}-S)^2} \int_{-\infty}^{\infty} \frac{d_{SD}}{\sqrt{d_{SD}^2+\xi^2+\eta^2}} p(\xi,\eta;\beta) h(\xi-\xi') d\xi d\beta$$

(weighting, projection, filter; filtering; backprojection)

- Slice thickness filter
  - $H_{ST}(w) = \frac{1}{2}\left[1+\cos\left(\frac{\pi w}{k_{ST}}\right)\right]$

- **Simultaneous algebraic reconstruction technique**
  - $Af = p$

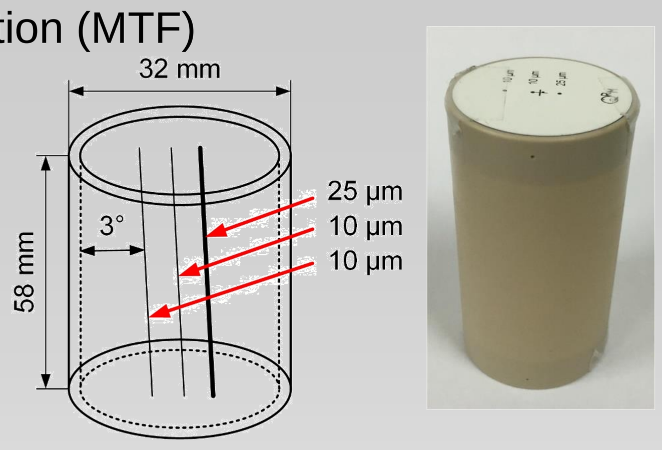


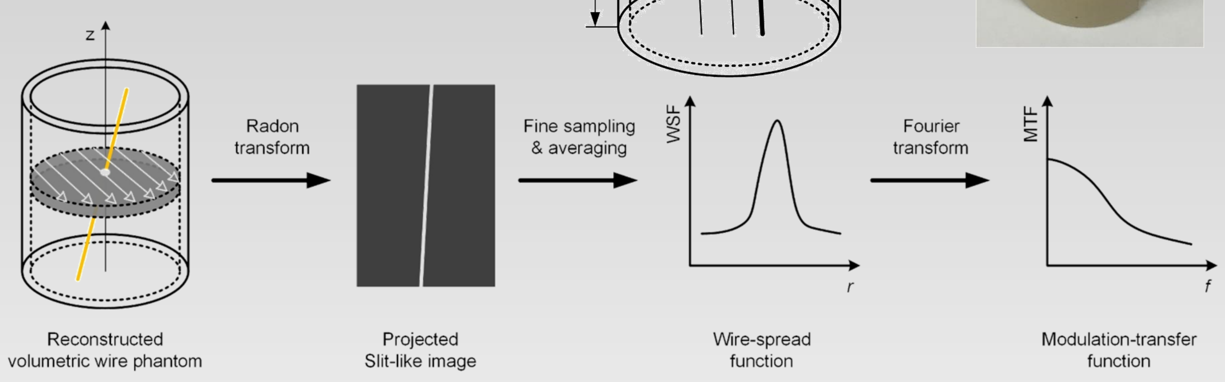
- $f^{(i+1)} = f^{(i)} + \frac{\sum \left[a_j \frac{p_j - a_j^T f^{(i)}}{\sum a_j} \right]}{\sum a_j}$

Stopping criterion

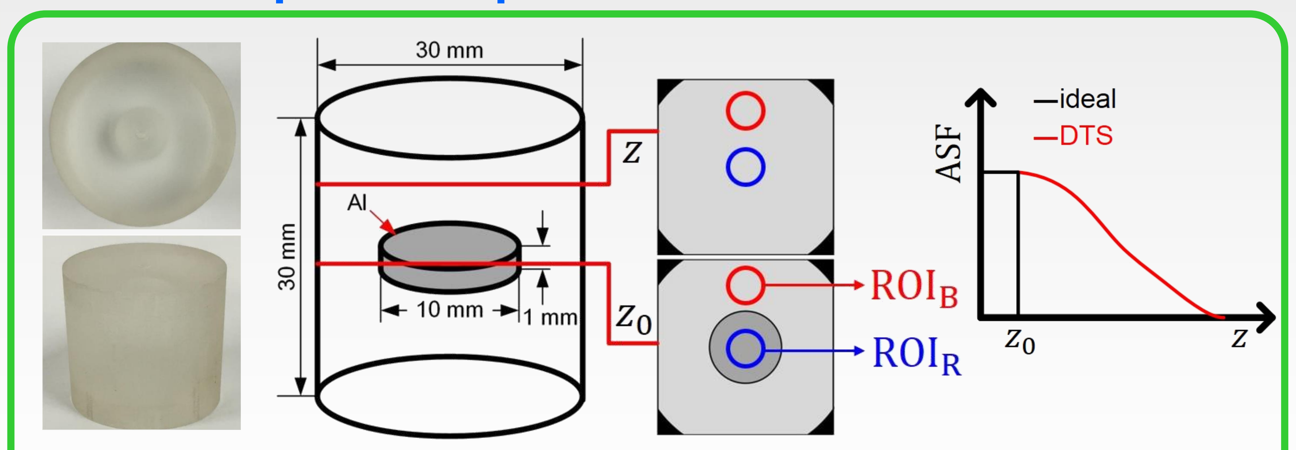
$$\epsilon = \frac{\frac{1}{N}\sum\sum\sum \left| f^{(i)} - f^{(i+1)} \right|}{\frac{1}{N}\sum\sum\sum \left| f^{(i)} \right|} = 0.03 - 0.05$$

- **Wire impulse response**
  - Modulation-transfer function (MTF)
  - $LSF(x) = \int PSF(x,y)dy$
  - $MTF(u) = FT\left\{\frac{LSF(x)}{\int LSF(x)dx}\right\}$



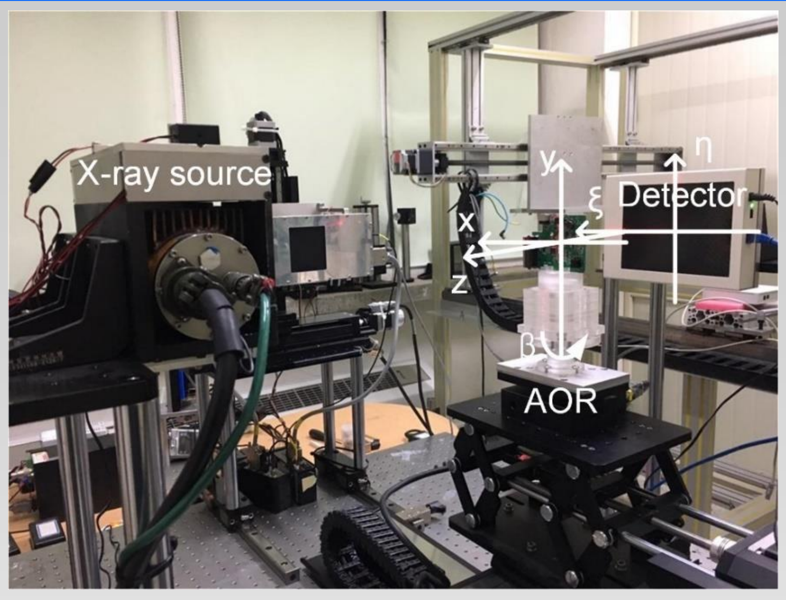


- **Disc impulse response**



- Signal difference-to-noise ratio
  - $SDNR = \frac{S_R(z_0) - S_B(z_0)}{\sigma_B(z_0)}$
- Artifact-spread function
  - $ASF = \frac{S_R(z) - S_B(z)}{S_R(z_0) - S_B(z_0)}$

- **Experimental information**



➢ Experiment setup

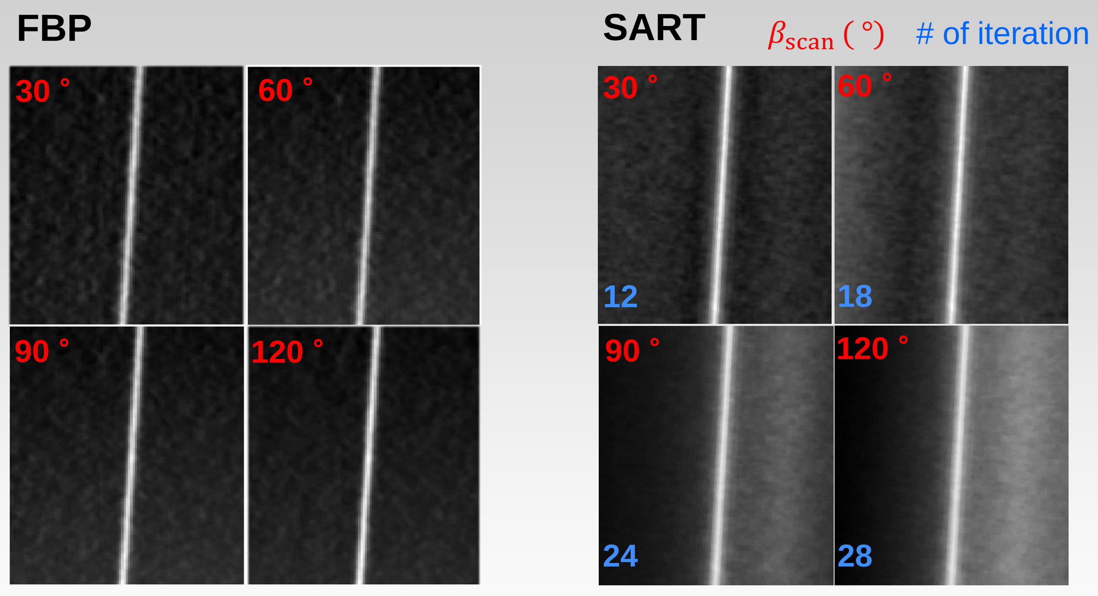
Tube voltage (kV)	45
Tube current (mA)	0.9
Readout time (ms)	200
Added filtration	2 mmAl
Source to detector distance (mm)	Disc : 614.9 Wire : 656.2
Magnification	2.0
Detector size	1548 X 1032
Pixel pitch (mm)	0.099

➢ Reconstruction information

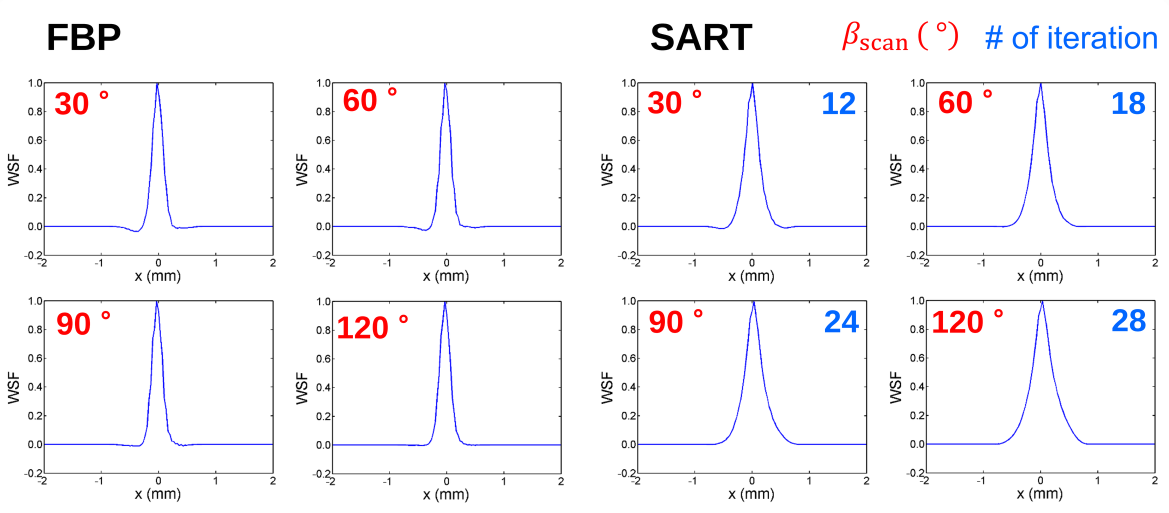
Scan angle (°)	30	60	90	120
Step angle (°)	1, 2, 3, 5	1, 2, 4, 6	3, 6, 9	4, 8, 12

Results

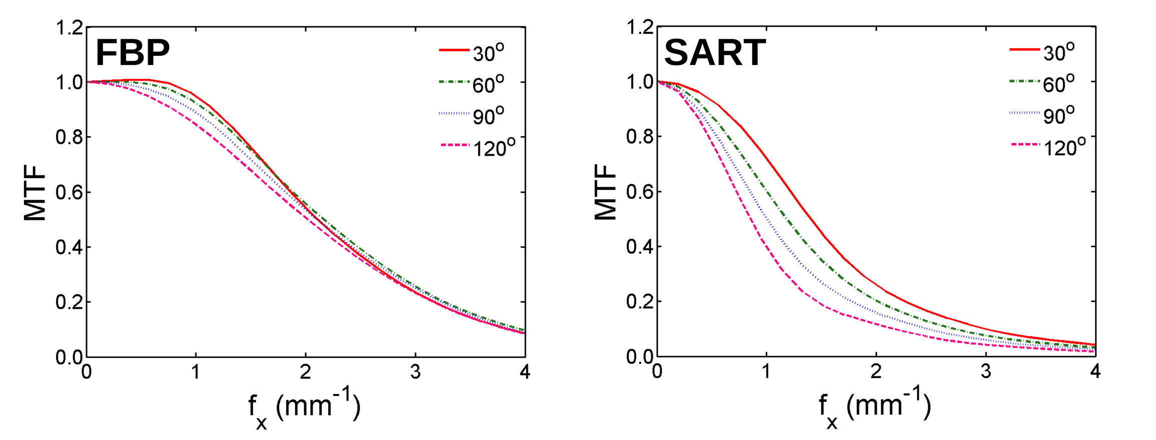
- **Reconstructed wire images for various scan angles**



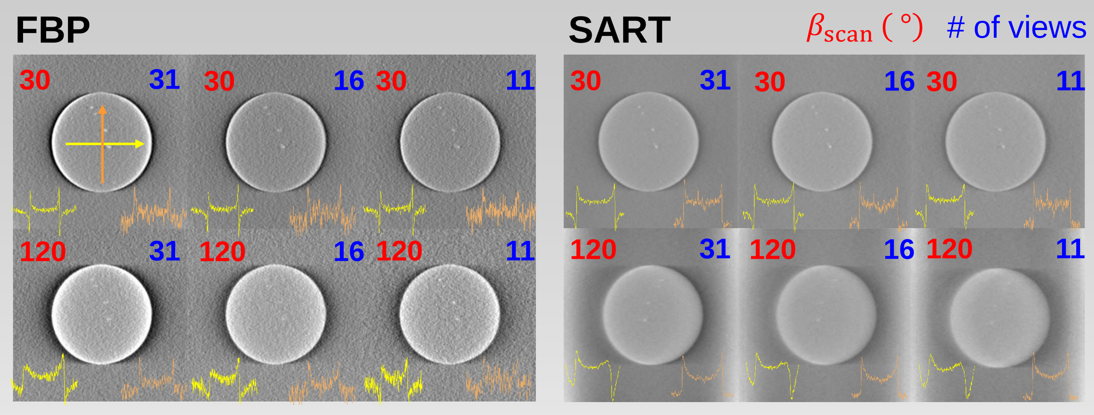
- **Wire spread function**



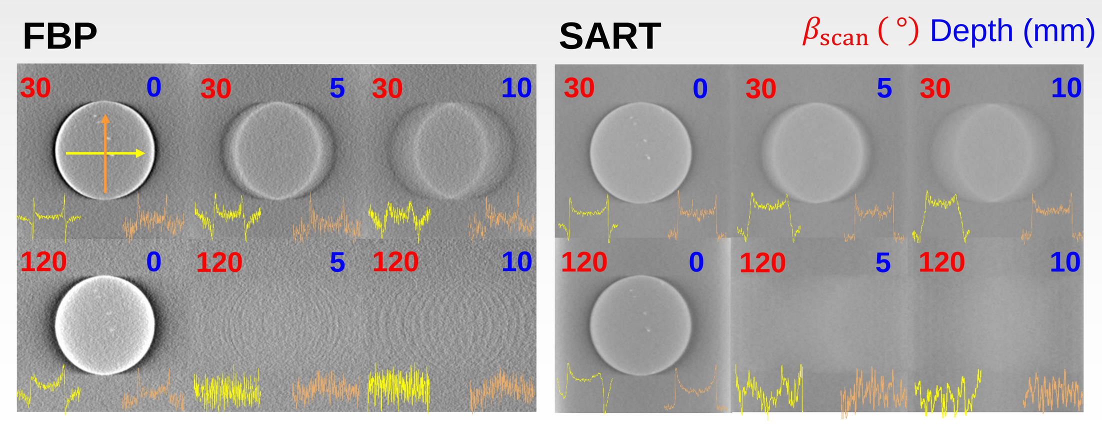
- **MTF results for various scan angles**



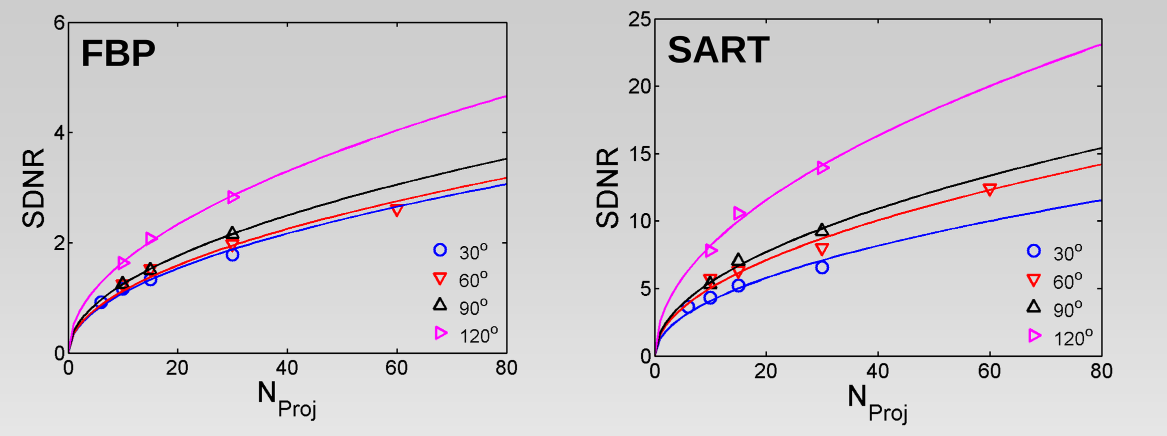
- **Reconstructed disc images at planes of interest**



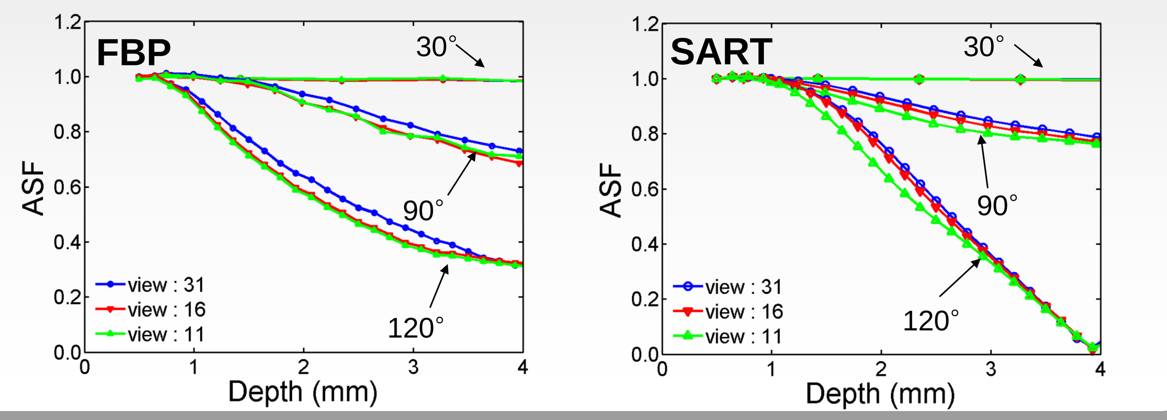
- **Reconstructed disc images along the depth direction**



- **SDNR results for various scan angle at planes of interest**



- **ASF results for various scan angles and various projection views**



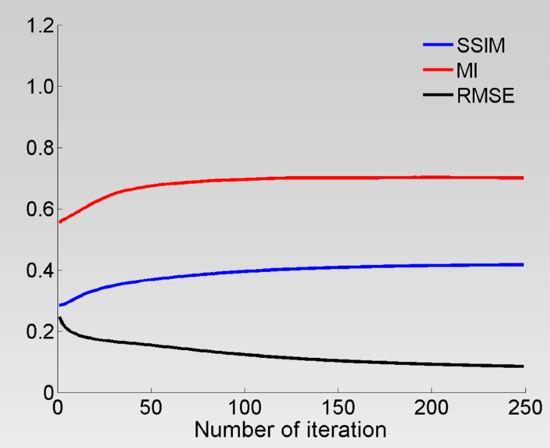
Discussion and Summary

- Numerical study
  - $SSIM = \frac{(2\mu_x\mu_y + (0.01)^2)(2\sigma_{xy} + (0.03)^2)}{(\mu_x^2+\mu_y^2+(0.01)^2)(\sigma_x^2+\sigma_y^2+(0.03)^2)} \le 1$
  - $MI = \sum_{y\in Y}\sum_{x\in X} p(x,y)\log_2\left(\frac{p(x,y)}{p(x)p(y)}\right) \le 1$
  - $RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(X-Y)^2}$

➢ FBP

SSIM	0.9266
MI	0.6594
RMSE	0.0546

➢ SART



- Common observations both in the FBP- and SART-based DTS methods
  - SDNR increases with $\sqrt{N_{proj}}$ and β_{scan}
  - ASF (or the depth resolution) improves with β_{scan}
  - ASF is independent on N_{proj}
- Different observations between the FBP- and SART-based DTS methods
  - The FBP shows the better in-plane MTF performance than the SART
  - On the contrary, the SART is better than the FBP in both the SDNR & ASF performances
- The FBP DTS is preferred for a high-resolution real-time inspection system, whereas the SART DTS may be used for a system requiring high-quality images with less image noise and less artifacts

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