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

Seungwoo Ha*, Jonghee Yun*, Bitbyeol Kim*, Jinwoo Kim* and Ho Kyung Kim**

*School of Mechanical Engineering, Pusan National University, Busan 46241, Republic of Korea
**Center for Advanced Medical Engineering Research, Pusan National University, Busan 46241, Republic of Korea
Corresponding author: kimbite@pusan.ac.kr

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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 (Δα) [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 Δα) 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 Δα in a reasonable inspection time, but the smaller Δα may restrict the inspection time
• For a given inspection time, the measurement of projection at the small Δα is challenging

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 α + Δα, two processes are required: coordinates transformation and interpolation process

- Coordinates transformation
  • Relationship between coordinates
    \[ \hat{u} = x \sin \alpha + y \cos \alpha, \hat{v} = \hat{z} \]
  • Conversion of object to detector coordinates
    \[ u_i = d(x_i \sin \alpha + y_i \cos \alpha), \quad v_i = d(y_i \cos \alpha + x_i \sin \alpha) \]
  • Interpolated coordinates
    - \( x_i \) can be assumed to zero at thin objects
      \[ (u_i, v_i) = \left( \frac{m_\alpha \cos \theta}{m_\alpha \cos \alpha}, \frac{m_\theta}{m_\alpha} \right) \]
  • Coordinates-transform operator
    \[ R^d(u_i, v_i) = P_\alpha(u_i, v_i) \]
  • Interpolation process
    - The weighting factor for the images obtained at α & α + Δα
      \[ P_\alpha(u_i, v_i) = w_\alpha R^d(u_i, v_i) + (1 - w_\alpha) R^d(u_i+\Delta\alpha, v_i) \]

Results

• Experimental results
  \[ \Delta\alpha \quad 1^\circ \quad \text{PI (5°→1°)} \]
  \[ 5^\circ \]

Profile

SNR (HU)

3.0156
2.5748
2.1718

ROI: Region of interest

Objective

• We suggest a Δα-reduction method that augments the number of projection data by using a projection-interpolation (PI) method for projection images obtained at coarse Δα
  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 Δα

Analysis & experiment

• Signal-difference-to-noise ratio (SDNR)
  \[ \text{SDNR} = \frac{S_{\beta}(z_0) - S_{\beta}(z_0 - \Delta z)}{\sigma_{\beta}(z_0)} \]
• Artifact spread function (ASF)
  \[ \text{ASF} = \frac{S_{\beta}(z_0) - S_{\beta}(z_0 - \Delta z)}{S_{\beta}(z_0)} \]

• Operators
  \[ R^d(u_i, v_i) = \text{Coordinates-transform operator from the detector plane at } \alpha \text{ to } \alpha' \]

• Parameters
  \[ (x, y, z) \quad \text{Global coordinates} \]
  \[ (u_i, v_i) \quad \text{Local coordinates} \]
  \[ (u_0, v_0) \quad \text{A target voxel in the global coordinates} \]
  \[ P_\alpha(u_0, v_0) \quad \text{A projected target voxel on the detector plane} \]

• Geometric and interpolation parameters
  \[ \alpha \quad \text{Projection angle} \]
  \[ d \quad \text{Source to detector distance} \]
  \[ \theta \quad \text{Interpolation angle} \]
  \[ m_\alpha \quad \text{Magnification of a target voxel at } \alpha \]
  \[ \Delta\alpha \quad \text{Step angle} \]
  \[ r \quad \text{Source to object distance} \]

• Numerical disc phantom for analysis

• Experimental conditions

| Experimental setup | | | | |
|--------------------|------|----------------|
| SDD | SOD | Al-filter |
| kVp | mA | Integration time |
| 49 kVp | 0.9 mA | 250 ms |
| Det. size | Pixel size | Voxel size |
| 1544 x 1532 | 0.069 mm | 0.045 mm |
| Recon. size | Scan angle | Step/interp. angle |
| 512 x 512 | 120° | 5° |

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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