Planar cone-beam computed tomography with a flat-panel detector

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Research motivation
- X-ray cone-beam computed tomography (CBCT) has been widely used for industrial nondestructive testing and quality control of products.
- Although improvement in the density of multilayer printed circuit boards (PCBs) and electronic chips/packages highly demands precise defect-detecting techniques, the typical CBCT scanning is impractical for the PCB inspection because of its thin slab geometry.

Objectives
- For the PCB inspection, we develop a bench-top planar CT (pCT) system, which adopts the "tomosynthesis" technique that can produce cross-sectional images parallel to the axis of rotation for a limited angular range.
- We evaluate the imaging performance of the pCT system in comparisons with the conventional CBCT technique. The imaging performance includes the modulation-transfer function (MTF), noise-power spectrum (NPS), noise-equivalent number of quanta (NEQ), artifact spread-function (ASF), and signal difference-to-noise ratio (SDNR).

Materials and Methods

- System description

  - X-ray source
    - Filtration: 1 mmAl
    - Nominal focal-spot size: 35 μm
    - Max. voltage: 50 kVp
    - Max. beam current: 1 mA

  - Detector
    - Scintillator: 33.91 mg/cm²
    - Photodiode pixel format: 1548 x 1032 pixels
    - Pixel pitch: 99 μm
    - Max. frame rate: 20 fps

  - Motions
    - Max. ranges: x-y-z directions 300 – 600 – 75 mm
    - Max. source-to-detector distance: 656.2 mm

- NEQ(f₀, f₁, f₂) = \( f \theta_{tot} \)
- MTF(f₀, f₁, f₂) = \( f \theta_{tot} \)
- NPS(f₀, f₁, f₂) = \( f \theta_{tot} \)

Reconstruction algorithm
- CBCT: FBP + Hanning filter
- pCT: FDK algorithm + apodization filter, slice thickness filter

Results
- MTF
  - Ideal MTF implies the detector MTF considering the magnification factor of 2.
  - The MTF measured from the CBCT technique (simply, CBCT MTF) is lower than the ideal MTF because of the CBCT reconstruction operations.
  - Surprisingly, the pCT technique shows a higher MTF performance (simply, pCT MTF) than the ideal MTF in the frequencies less than 5.5 mm⁻¹.
  - The characteristic of the pCT MTF can be explained by the measured LSF.

  - Both the CBCT and pCT MTFs are nearly independent of the given x-ray energies (40-50 kVp).

- Reconstruction image
  - CBCT reconstruction image shows a better depth resolution than pCT.

- NPS and NEQ
  - The CBCT incorporating the Hanning filter shows the low-pass filtering trend in the NPS results, and the spectral densities increases with increasing the applied voltage.
  - Shape and properties of the pCT NPS are similar to those of the CBCT NPS, but the bandwidth of the pCT NPS is wider than that of the CBCT NPS.
  - Spectral densities of the pCT NPS are larger than those of the CBCT NPS because of the high band-limited MTF characteristic.
  - The characteristics of NEQ follow those of NPS except that the energy dependencies are opposite. The pCT NEQ performance outperforms the CBCT.

- Evaluation in various scan angle
  - The pCT MTF converges to the CBCT MTF as the scan angle is increased.
  - The spectral densities of the pCT NPS decreases with increasing scan angle while those of the NEQ increases.

- Discussion and conclusion
  - According to the Fourier metric performance results, the pCT shows a better MTF but a worse NPS than the CBCT.
  - The depth resolution of the pCT enhances but the SDNR degrades with the increasing scan angle.
  - The scanning angular range of the pCT system should be optimized accounting for what size and contrast are investigated.