Digital X-ray Tomosynthesis of Very Thin-Slab Objects

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1. Introduction

In the manufacturing industry, the discrimination of products containing defects is one of the most important procedure. For this procedure, various x-ray imaging techniques, such as computed tomography (CT) [1], computed laminography [2], and digital tomosynthesis (DTS) [3, 4], have been widely used.

The DTS method, also known as the limited angle tomography, is particularly appropriate for the investigation of thin-slab objects such as printed circuit boards (PCBs). The DTS method in a step-and-shoot fashion can, however, suffer from the trade-off between the image quality and the time for inspection. While a wide scan angular range with dense step angles can provide images with less noise, it is time-consuming. In contrast, a narrow scan range with sparse step angles can reduce the inspection time, but which can cause severe artifacts on the resultant image.

To enhance the image quality obtained with sparse projection views in DTS, in this study the projection-based interpolation method is introduced. This interpolation method is based on the assumption that the object is infinitesimally thin. The performance obtained from the proposed method is compared with that from the conventional method.

2. Methods

2.1 Geometric correction

When incident x-rays irradiate a thin-slab object in the circular scanning framework, the coordinates of the projected object on the detector plane is mainly determined by the projection angle θ . On the other hand, interpolation between two projections requires *a priori* the re-size of the two projections.

Shrinkage of a projection can be described by

$$L_{i,j} = L_i \frac{\cos(\theta_i + \tau_j)}{\cos(\theta_i)} \frac{d - W\sin(\theta_i)}{d - W\sin(\theta_i + \tau_j)}, \qquad (1)$$

where θ_i denotes the projection angle of the *i*-th projection, τ_j denotes the angle between the *j*-th estimated projection and the *i*-th projection, L_i denotes the width of *i*-th projection, $L_{i,j}$ denotes the width of resized image from the *i*-th projection to the *j*-th estimated projection. d and W denote the source-to-object distance and the width of the object, respectively.

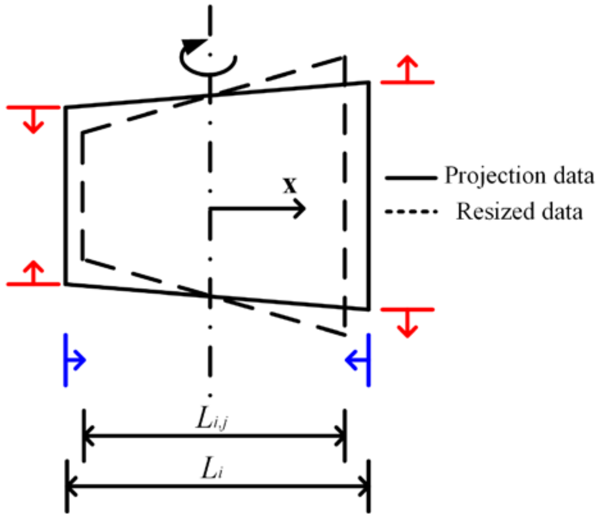

Fig. 1. The size of the *i*-th projection data and that of the *i*-th projection data resized to the *j*-th estimated data.

Similarly, expansion of a projection is given by

$$L_{i+1,j} = L_{i+1} \frac{\cos(\theta_i + \tau_j)}{\cos(\theta_{i+1})} \frac{d - W\sin(\theta_{i+1})}{d - W\sin(\theta_i + \tau_j)}. \qquad (2)$$

Since magnification changes with respect to rotation, changed for each column, the size of projection in the orthogonal direction is also changed. The modification of height from the *i*-th projection to the *j*-th projection is given by

$$H_{i,j}(x) = H_i(x) \frac{d - W(x)\sin(\theta_i)}{d - W(x)\sin(\theta_i + \tau_j)}, \qquad (3)$$

where $H_{i,j}(x)$ denotes the height of the resized projection at the *x*-column, $H_i(x)$ denotes the height of the *i*-th projection at the x -column, and $W(x)$ denotes the width direction length of the object corresponding to the *x*-column in the image.

The equation for the height modification from *i+1*-th projection to *j*-th projection is following:

$$H_{i+1,j}(x) = H_{i+1}(x) \frac{d - W(x)\sin(\theta_{i+1})}{d - W(x)\sin(\theta_i + \tau_j)}, \qquad (4)$$

Figure 1 shows a sketch describing the sizes of the *i*-th projection of an object and its resized projection to the *j*-th estimated data.

2.2 Interpolation

From the resized two projections, a simple linear interpolation determines an estimated projection:

$$E_{i,j} = (1-\omega_j)I_{i,j} + \omega_j I_{i+1,j}\,, \tag{5}$$

where $E_{i,j}$ denotes the j-th estimated image interpolated by the neighboring projections (i.e., the i-th and $i+1$-th projections), $I_{i,j}$ denotes the resized projection from the i-th projection to the j-th estimated image, and ω_j denotes the weighting factor depending on the j.

3. Preliminary results

Figure 2 compares the reconstructed image of sample PCBs (Bar pattern phantom and ASUS SupremeFX) obtained at the scan angular range of 20 degrees with a step angle of 10 degrees and that obtained with 21 projections using the interpolation. Although the interpolation method results in blurred image, the out-of-plane artifact is reduced. It is noted that the conventional filtered backprojection algorithm is used for reconstruction [5].

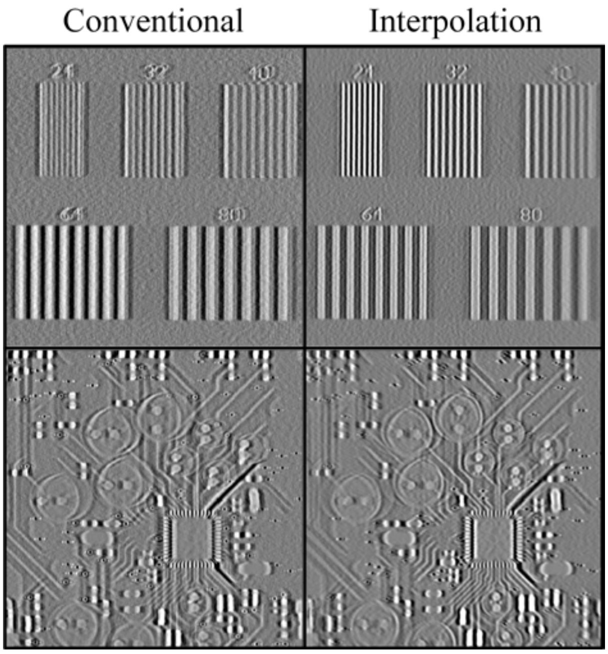

Fig. 2. The reconstructed images of the phantoms at the scan angular range of 20 degrees with the step angle of 10 degrees, and the images after the interpolation mimicking the use of 21 projections.

4. Further study

The usefulness of the proposed method will be investigated using quantitative phantoms including numerical simulations. The limitation of the method, which assumes the object to be infinitesimally thin, will also be quantitatively addressed.

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