Some Considerations on Image Reconstruction
–A description of filtered back projection and iterative reconstruction–

Naoki Kubo, PhD, Associate Professor

Introduction

The following two duties are expected of us: (1) to assist in interpretation of diagnostic images, and (2) to provide detailed explanations of radiological examinations.

As professionals, we owe it to our clients to maintain our competence in perceiving the reality of each person's condition during radiological examinations; we must neither underestimate their radiation exposure risks nor overestimate the benefits they may receive from the examination.

When assisting in interpretation of diagnostic images, we must understand the characteristics of images that can affect our assessment. Moreover, turning to the topic of reconstructed images, much information can be gathered from images utilizing the full capability of reconstruction algorithms. Image quality is highly dependent upon the method of reconstruction (calculation of tomographic images). Reconstruction can be broadly classified into the following two types: filtered back projection and iterative reconstruction.

Filtered back projection

Projection data do not provide location information concerning the depth direction; therefore, the following approach has been conceived for reconstruction of tomographic images. First, all the projection data due for reconstruction are read in from the image; i.e., the data are assumed to be uniform from the foremost point to the rear, with respect to the detectors. This step alone does not provide a tomographic image. Next, the process of data collection is repeated from a different angle, and this is carried out for all projection data. This is called "simple back projection". A problem with simple back projection, however, is that positive values remain in locations exterior to the actual physical object being scanned (the subject). This causes extremely blurry tomographic images. Therefore, the edges are enhanced in the projection data before the back projection is carried out. This enhancement cancels out the blurring in simple back projection, providing clear tomographic images. Edge enhancement is accomplished using a filter. The blurring arising in simple back projection is well understood, so a filter can be calculated to cancel it. There are two algorithms that can be applied to projection data, a Fourier transform in frequency space and a convolution in real space.

The method employing convolution is sometimes called “convolution back projection”. The above are the filtered back projection methods.

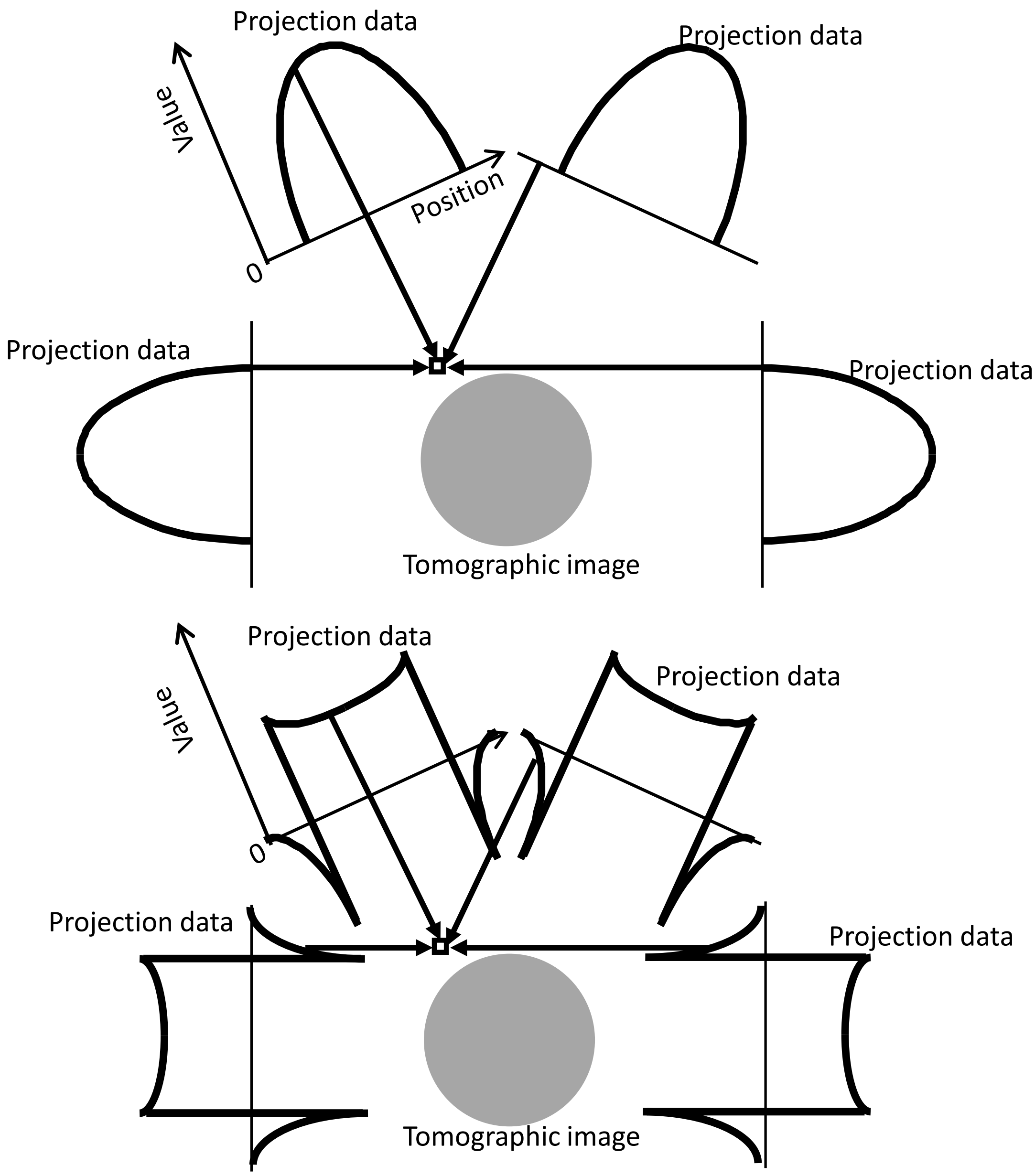


Figure 1 Simple back projection (upper portion), filtered back projection (lower portion)

Let us consider the case of a circle used as the subject. The projection data take the semi-elliptical distribution shown in the upper portion of Fig. 1. When these are back-projected, projected data values are summed, leaving non-zero values, in locations including those where the subject was never actually present. When these projection data are corrected with a filter function, negative values are assigned to the above locations, as in the lower portion of Fig. 1. When both are back-projected, the positive and negative values cancel each other out in the locations where the subject did not exist.

However, this filtered back projection still leaves some traces, and due to the finite step size of the sampling angles, it can leave star artifacts.

Iterative reconstruction

This begins with an assumption of the tomographic image. Forward projections are created in various directions based on the anticipated probability of detection by the detectors. When the projection data from this process match with the data gathered in actual measurements, the assumed tomographic image can be deemed correct. When the results in the forward projection of the assumed distribution are lower than the actual findings, the pixel values in the tomographic image are augmented, and conversely, they are decremented when the forward projection results are greater than the actual findings. Thus, the tomographic image is edited so as to equalize its data with the previously gathered projection data. A correction is then repeated by forward projection. This method of reconstruction is called "iterative reconstruction". It is common to use empirical methods to set the number of iterations of this process.

Many studies have examined ways to correct tomographic images that are assumed from projection data. A method called maximum likelihood expectation maximization (ML-EM) has become increasingly popular recently. This calculates plausible (maximum likelihood) tomographic images, as it assumes that the radiation count varies according to the Poisson distribution.

This procedure involves multiplying pixel values by coefficients. It provides correction to tomographic images; therefore, it is not permitted to assume that the initial pixel values of tomographic images are zero. It is common to start from some convenient uniform distribution. Because of this, there is a small difference between the maximum and minimum values in the image at low iteration numbers, i.e., the image then has low contrast.

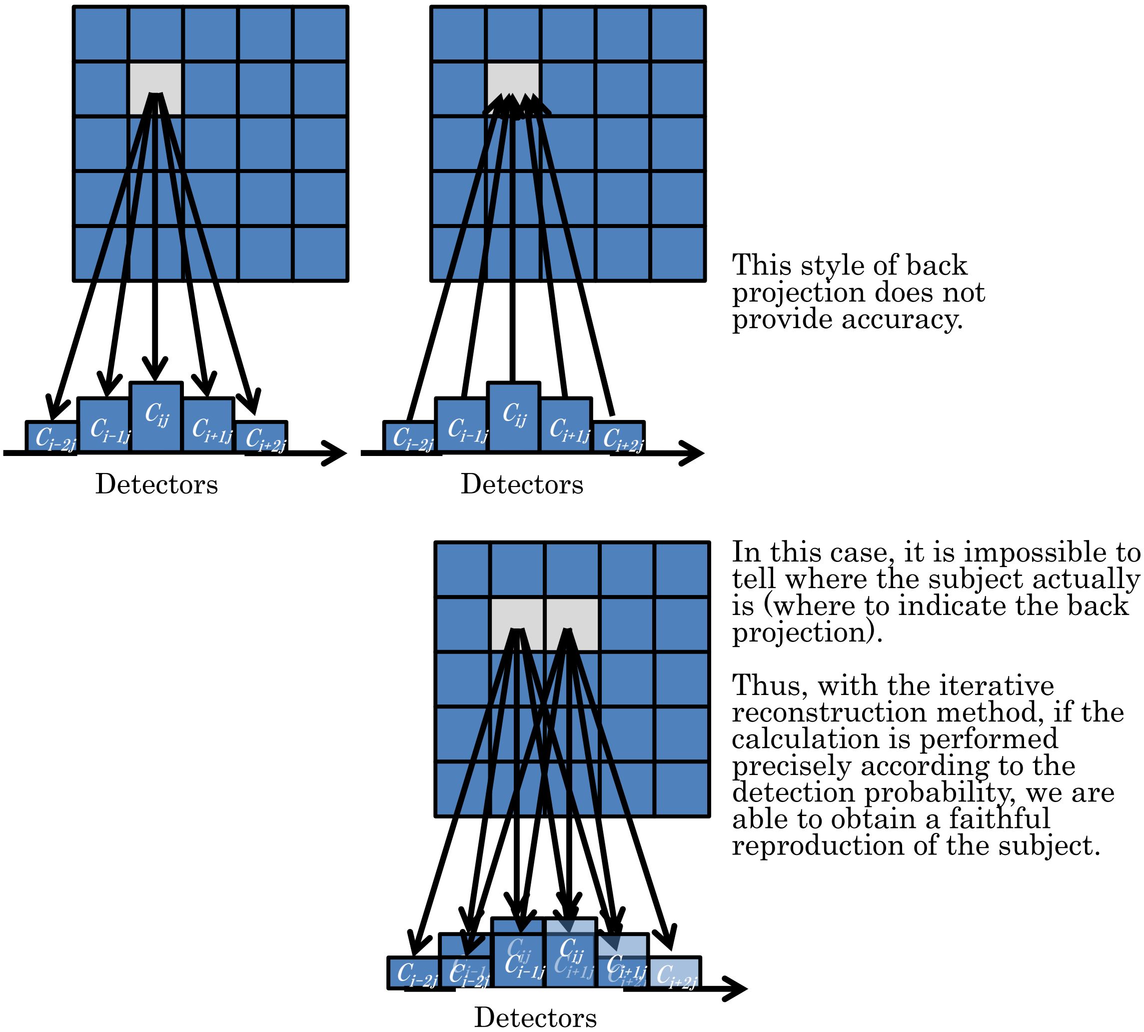
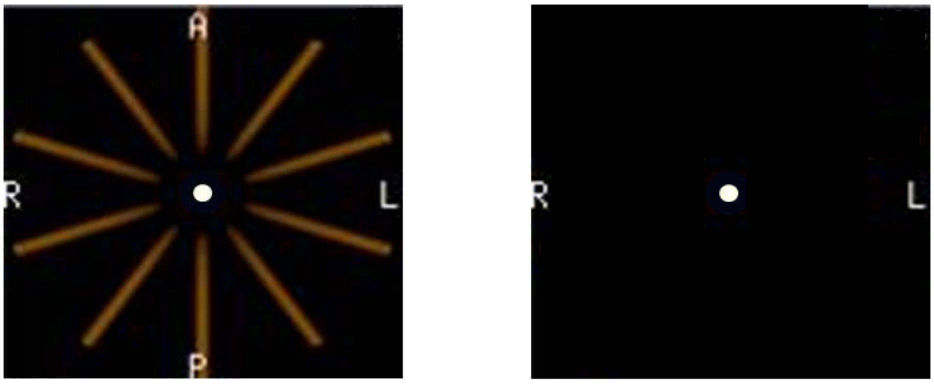


Figure 2 Explanation of why the easily comprehensible method of successive approximation for correcting blur lacks accuracy. Example of two neighboring pixels: Direction of back projection cannot be identified (lower right).

One of the advantages of the iterative reconstruction is that it incorporates a correction for the weakening of spatial resolution (blurring) because it sets the detection probability of the detectors to the appropriate level. However, Fig. 2 presents an explanation of how this correction, though easy to understand, degrades accuracy. We can represent the blurring of a point as shown in the upper left portion of Fig. 2. As indicated in the upper right of Fig. 2, it would be a mistake to have confidence in the accuracy of this back projection. Back projection from this pixel is not limited to a single pixel. In the case of two contiguous pixels (lower right of Fig. 2), it becomes impossible to tell where the subject actually is and where to indicate the back projection. Thus, we can also interpret this to mean that we can arrive at a faithful reproduction of the subject with the iterative reconstruction if the calculation is performed precisely according to the detection probability.

Variations in image quality

The principles of the filtered back projection method make it prone to star artifacts (running in the same orientation as the back projection). In contrast, such artifacts are rare with iterative reconstruction (Fig. 3).



Filtered back projection Iterative reconstruction

Figure 3 Contrast between methods in occurrence of star artifacts

Iterative reconstruction is also able to reduce the scatter of pixel values. For this reason, it can be expected to provide better resolution of low-contrast images than filtered back projection (Fig. 4).

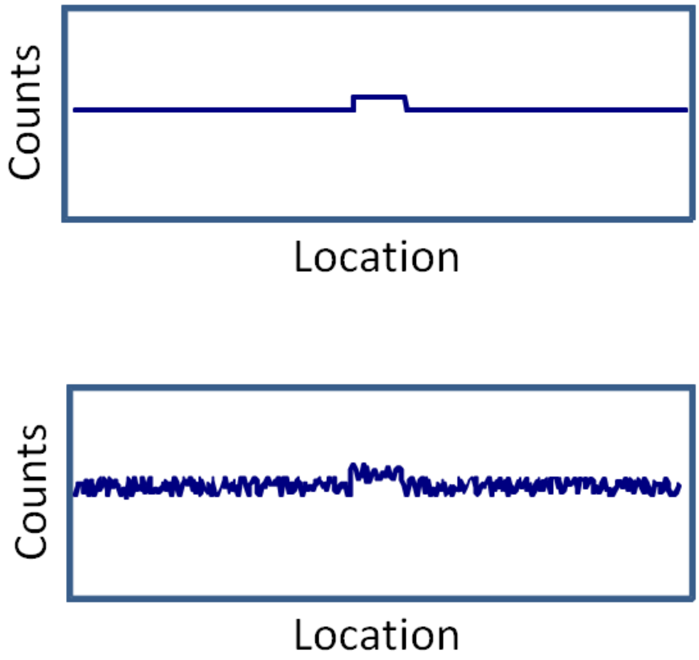


Figure 4 Pattern diagrams illustrating how low-contrast regions can become hard to distinguish due to statistical noise. Examples show a no-noise case (upper) and a case with statistical noise (lower)

A factor to bear in mind while acquiring images is whether the statistical noise (scatter of pixel values) is so high that the signal is completely lost. No method of reconstruction will provide a usable image in such circumstances, and the examination would be worse than useless; it would expose the client to a needless dose of radiation. It is vital to ensure good exposure conditions.

Conclusion

It is up to the medical practitioner to encourage patients faced with decisions regarding medical treatment against despair by treating them in a competent manner, reassuring them in the face of severe pain, and helping to abolish their fear of suffering or even death if left untreated.

In providing medical treatment, it is important to balance the risks of exposure to radiation against the benefits to the patient. A paper in *Lancet* (2012) concluded that cumulative exposure of a child to 50 mGy during computed tomography scans might triple their risk of leukemia. Therefore, it is necessary to reduce patients' exposure to radiation as much as possible, to near zero. This is an obligation of the specialists who understand these images and the power of radiation, and should be an effective way to reduce risks to patients.

References

Pearce MS, Salotti JA, Little MP, et al.. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 2012;380(9840):499–505.