Reconstruction Filtering in Industrial gamma-ray CT Application

Lakshminarayana Yenumula, Rajesh V Acharya, Umesh Kumar, and Ashutosh Dash*

Industrial Tomography and Instrumentation Section, Isotope Production and Applications Division, Bhabha Atomic Research Centre, Mumbai – 400085, India

91 22 2599 0180, laxmany@barc.gov.in

Abstract

Industrial gamma-ray Transmission Computed Tomography (TCT) scanning is used in Single Photon Emission CT (SPECT or ECT) imaging to obtain attenuation maps. The knowledge of attenuation due to waste matrix is required to characterize activity level and distribution of gamma emitting radioisotopes inside nuclear waste containers.The attenuation maps are generally noisy due to lesser sampling and less available photon statistics in data collection. Image noise and spatial resolution play very important roles in image quality. The problem of noise in TCT is usually handled with the application of low-pass digital filters. No single set of filter parameters stands out as being best for all applications. Each application requires careful study and evaluation of filter parameters to match test constraints and requirements. In this study, effects of filter parameters have been evaluated for Industrial γ-ray CT application. The experimental projection data were acquired on a prototype waste drum using a collimated Cs-137 (~12.6 mCi) radioactive source and □ 1 inch x 1 inch NaI(Tl) scintillation detector with associated electronics. The attenuation maps were reconstructed using filtered back-projection technique. Various low-pass filters combined with Ramp filter were applied during tomographic image reconstruction.The quantitative analysis of the filters has been carried out based on RMS contrast and Signal-to-noise ratio (SNR). The results suggest that the optimum cutoff frequency and filter should be determined to obtain optimum image quality by referring to the type of analysis and application.

Keywords: Emission Computed Tomography (ECT), Transmission Computed Tomography (TCT), digital filters, RMS contrast, Signal-to-noise ratio (SNR)

----

1. Introduction

The problem of noise in Computed Tomography (CT) is usually handled with the application of smoothing filters. The smoothing filter is a low-pass digital filter designed to reduce higher-frequency components to a defined degree. The low-pass filters are characterized by two parameters: cut-off frequency and order. The cut-off frequency or roll-off frequency or critical frequency defines the frequency from which higher frequencies will be suppressed and therefor denotes the bandwidth of the filter. Nyquist frequency (Nq) represents the maximum frequency measurable by the applied device and is apparently the highest cutoff frequency for a filter. The cutoff frequency is expressed in cycles per pixel or a fraction of the Nq frequency. The value of the cutoff frequency determines how the filter will affect both image noise and resolution. Low cut-off frequency provides good noise suppression, but blurs the image whereas higher cut-off frequency can preserve the resolution, but does not suppress noise sufficiently. Selecting the cut-off frequency determines the size of the objects that will be removed from the image. It is desirable to remove very small objects (higher frequencies) from the image because they correspond to noise and preserve larger objects (lower frequencies) that contain structural information. The criteria can be used to set the cut-off frequency to a value approximately equal to the resolution of the detector. This way, all of the information in the image that describes resolvable structures is kept and smaller noise is removed [1]. Some filters are defined by a second parameter, order of the filter (e.g. Butterworth filter). Higher order filters (sharp edges) should be avoided since they can introduce oscillations (ripple artefacts) in the image [2].

In order to reduce the noise content of CT projection data, smoothing filter operation combined with ramp filter (which is a high-pass filter) is performed on the projection data before reconstruction. This gives rise to the following equation in the frequency domain.

$$G = F \times W_S \times H_R \qquad (1)$$

Where, F represents Fourier transformation of the projection data, W_S smoothing filter and H_R Ramp filter. Multiplication of Ramp filter and a low-pass filter together results in a band-pass filter.

Since there is no universal filter and set of filter parameters for all applications, various filters have been proposed in literature such as Shepp-Logan, Hamming, Hanning, and their modified version with Ramp filter for tomographic reconstruction [3-4]. Each application requires careful study and evaluation of filter and its parameters to match test constraints and requirements. Ramp filter and four different low-pass filters combined with ramp filter have been implemented in this study. The aim of this paper was to optimize filter parameters for Industrial □-ray CT application.

2. Materials and Methods

In this section, we present the experimental details and quantitative metrics used to compare the effect of various filters on reconstructed image quality.

2.1 Experimental

Schematic diagram of the experimental set-up used to acquire data with first-generation scan geometry is shown in figure 1. The set-up consists of a Lead collimated □1inch x 1 inch NaI(Tl) scintillation detector, a Cs-137 (~12.6 mCi) radioisotope source and a 3-axis sample manipulator. The detector aperture is defined by lead collimator with 10 mm cylindrical hole in front of the detector. A prototype nuclear waste drum was used as an object to evaluate attenuation map. It is a steelcontainer of 200 mm diameter and 300 mm height with an Aluminum rod of 40 mm diameter and a Perspex rod of 60 mm diameter. Scanning was done at the center of drum height. Data were acquired by rotating the specimen over 360 degree with an acquisition time of 30 seconds per projection for 36 projections.

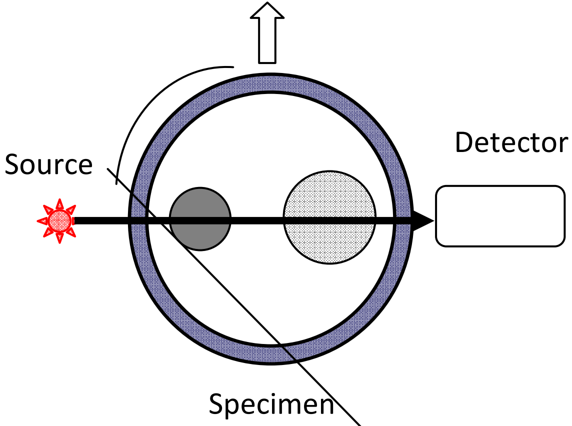

Source
Detector
Specimen

Figure 1: Schematic diagram of experimental setup

2.2 Quantitative Evaluation Parameters

To optimize the filter, two parameters were used for quantitative analysis: RMS contrast and Signal-to-noise ratio (SNR). RMS contrast is computed using the root mean square method [5]:

$$\text{RMS contrast} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_i - \mu\right)^2} \quad (2)$$

Where f_i is intensity of i^{th} pixel of the two dimensional image having M pixels and μ denotes the average intensity of all pixel values in the image:

$$\mu = \frac{1}{N}\sum_{i=1}^{N} f_i \qquad (3)$$

Signal-to-noise ratio (SNR) describes how well an object will be seen by observer and it is given by

$$\text{SNR} = \frac{\mu}{\sigma} \qquad (4)$$

Where σ is the standard deviation which is a direct measurement of noise.

To assess optimal cutoff frequencies for the five filters, cutoff frequencies from 0.2 to 1.0 times Nyquist frequency (Nq) with step 0.005 were selected for each filter and attenuation images (CT slices) were reconstructed from filtered projection data using Filtered Back-projection (FBP) method.

3. **Experimental Results and Discussion**

The figure 2(a) shows the plot of various low-pass filters used in the study. From this figure it is clear that amplitude of each filter at Nq frequency depends on the type of filter. Figure 2 (b) and (c) show the reconstructed CT slices obtained from projection data filtered with only Ramp filter and combination of Hann and Ramp filter. Evaluation of these CT slices showed the highest SNR and the highest RMS contrast respectively out of all the used filters. SNR and RMS contrast of the filters used in the study are presented in figure 3 (a)-(e). These figures clearly show that for all the filters SNR decreases whereas RMS contrast increases with increasing cutoff frequency.Since the noise component is relatively small compared to the image content for low cutoff frequencies and the amplitude of noise is grater than the amplitude of image signal for high cutoff frequencies. So criteria in optimizing the cutoff frequency depends on the aim of study. This means that visual (RMS contrast) and quantitative (SNR) analysis require different criteria for the optimization of filter parameters such as cutoff frequency. In this study, purpose of optimization is to obtain 'optimum' image quality for visual and quantitative interpretation. Therefore the optimal cutoff frequency was determined from the intersection point of RMS contrast and SNR curves for each filter. Optimum cutoff frequencies of 0.30 Nq, 0.35 Nq, 0.45 Nq, 0.40 Nq and 0.35 Nq were obtained for Ramp filter and Shepp-Logan, Hamming, Hanning and Cosine filters combined with Ramp filter, respectively.

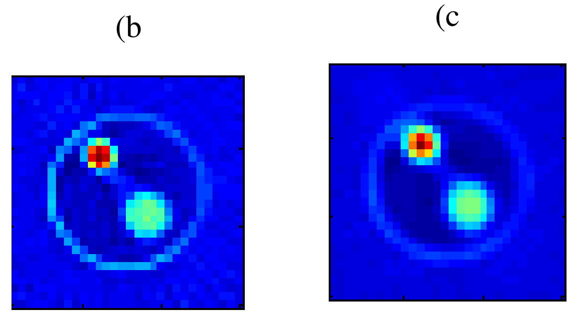
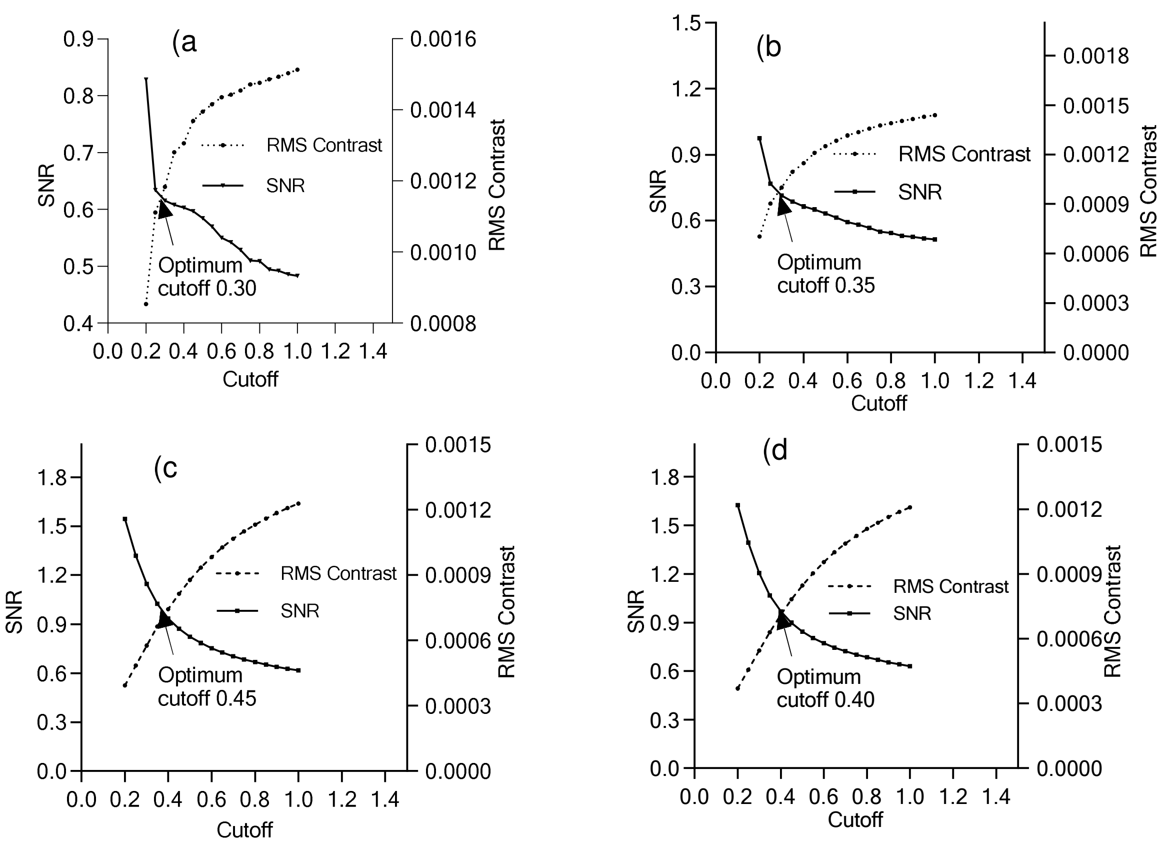


Figure 2: (a) Plot of varies low-pass filters combined with Ramp in relation to normalized frequency. Reconstructed CT slice of the specimen at cutoff value 1.0 by (b) only Ramp filtered projection data (c) Hann combined with Ramp filtered projection data.



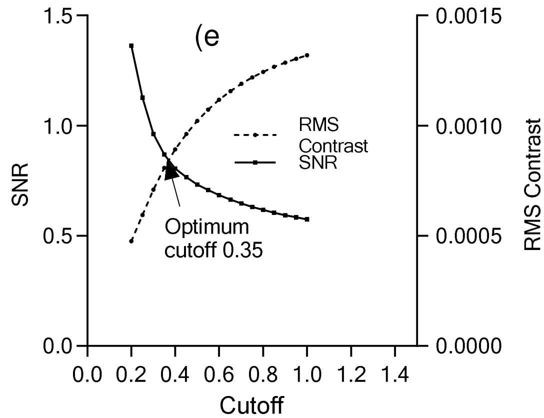


Figure 3: SNR and RMS contrast variation of varies low-pass filters with cutoff values (a) Only Ramp filter (b) Combination of Ramp and Shepp-Logan filter (c) Combination of Ramp and Hamming filter (d) Combination of Ramp and Hanning filter (e) Combination of Ramp and Cosine filter. (Cutoff frequency = cutoff x Nyquist frequency (Nq). In the present study Nq is 0.1 cm^{-1})

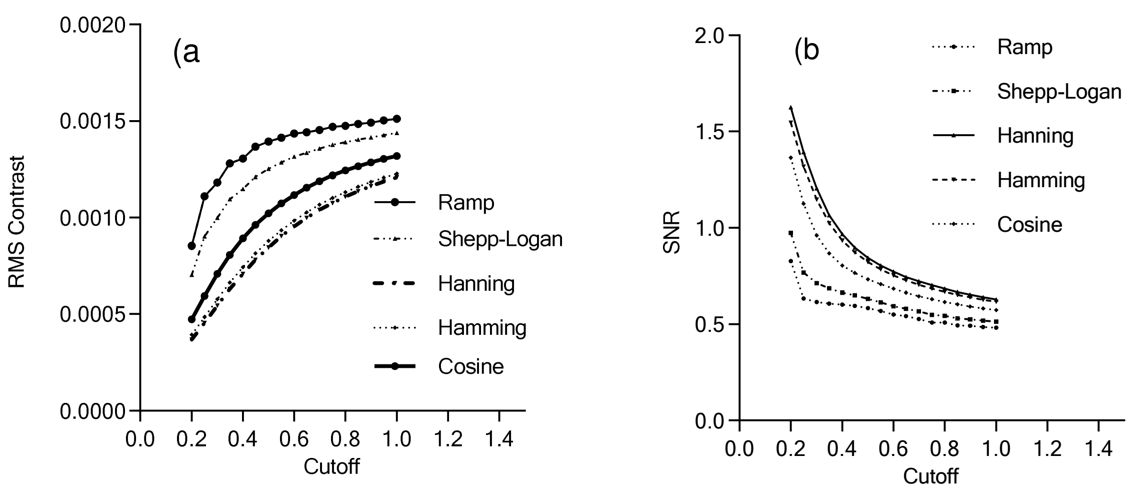


Figure 4: Comparison of SNR and RMS contrast of varies low-pass filters combined with Ramp filter.

The determination of optimum filter for qualitative and quantitative analysis would consider the ability of each filter in producing high RMS contrast and SNR at optimum cutoff frequency. Therefore, the RMS contrast and SNR for used five filters were calculated. Figures 4(a)-(b) show that RMS contrast and SNR have a constant relationship with cutoff frequencies for each filter. As the cutoff frequencies increase, SNR decreases since noise corresponds to high frequencies while RMS contrast increases. So separation of the noise and the object frequencies is dependent on the type of filter. Ramp filter is the best in producing RMS contrast and Hanning filter combined with Ramp produced the highest SNR values for all cutoff frequencies.

Conclusions

Evaluation of various reconstruction filters has been carried out for □-ray CT application using RMS contrast and SNR. The results show that different filters produced reconstructed images with different RMS contrast and SNR at different cutoff frequencies. Ramp filter produced the highest RMS contrast and Hanning filter combined with Ramp produced the highest SNR for all cutoff frequencies. So selection of filter should consider the application and type of analysis. This study should help to reduce the time spent in the selection of a smoothing filter, which is used in □-ray CT applications.

Acknowledgments

The authors acknowledge Dr. K.L. Ramakumar, Director, Radiochemistry and Isotope Group, BARC for his support and encouragement.

References

1. George Zubaland Gary Wisniewski, “Understanding fourier space and filter selection,” *Journal of Nuclear Cardiology,*Volume 4, Issue 3, Pages 234–243, 1997.

2. Van Laere K, Koole M, Lemahieu I, Dierckx R, “Image filtering in single-photon emission computed tomography: principles and applications,” *Computerized Medical Imaging Graphics*, 25(2):127-33, 2001.

3. Maria Lyra and Agapi Ploussi, “Filtering in SPECT Image Reconstruction,” *International Journal of Biomedical Imaging*, Volume 2011, 2011.

4. Z. Bian, J. Ma, J. Huang, H. Zhang, S. Niu, Q. Feng, Z. Liang, W. Chen “SR-NLM: a sinogram restoration induced non-local means image filtering for low-dose computed tomography,” *Computerized Medical Imaging and Graphics*, 37 (4), pp. 293–303, 2013.

5. R. Gholipour-Peyvandi' , S.Z. Islami-Rad, R. Heshmati, S. Zaferanlouie, and M. Ghannadi-Maragheh, “Influence of gamma energy on the image contrast for material with different density,” *International Journal of Pure and Applied Physics,* vol. 42 (3-4), pp. 425-431, 2011.