Spatial Resolution Assessment in Low Dose Imaging

Akshata Navalli and Shrinivas Desai

Abstract Computed tomography has been reported as most beneficial modality to mankind for effective diagnosis, planning, treatment and follows up of clinical cases. However, there is a potential risk of cancer among the recipients, who undergoes repeated computed tomography screening. This is mainly because the immunity of any living tissue can repair naturally the damage caused due to radiation only up-to a certain level. Beyond which the effort made by immunity in the natural repair can lead to cancerous cells. So, most computed tomography developers have enabled computed tomography modality with the feature of radiation dose management, working on the principle of as low as reasonably achievable. This article addresses the issue of low dose imaging and focuses on the enhancement of spatial resolution of images acquired from low dose, to improve the quality of image for acceptability; and proposes a system model and mathematical formulation of Highly Constrained-Back Projection.

Keywords Computed tomography · Low dose · Cancer · Radiation · Image quality

A. Navalli (✉)
Department of Computer Science, B.V.B College of Engineering & Technology,
Hubli 580031, India
e-mail: akshatanavalli06@gmail.com

S. Desai
Department of Information Science and Engineering, B.V.B College of Engineering
& Technology, Hubli 580031, India
e-mail: shree.desai07@gmail.com

A. Nagar et al. (eds.), *Proceedings of 3rd International Conference on Advanced Computing, Networking and Informatics*, Smart Innovation, Systems and Technologies 43, DOI 10.1007/978-81-322-2538-6_32

1 Introduction

The medical imaging has been benefited by the development of Computed Tomography (CT) and has contributed in effective diagnosis, treatment and managing complications in clinical domain. However, the concern towards the probable occurrence of cancer due to repeated CT scanning cannot be overlooked. Recently, a survey for estimating the risk of cancer due to usage of CT is carried out and reported to be 0.4 % in the United States alone. It is also estimated to be 1.5–2 % increment in this risk by the end of 2010 considering the trend in usage of CT [1]. The radiation doses during CT screening are approximately 50–100 times more, compared to the radiation doses in x-ray examinations [2]. As the dosage used during CT is much higher than conventional adding to risk of cancer, the CT developers are designing and coming out with a low dose protocol enabled CT units which work on the principle of As Low As Reasonably Achievable (ALARA) [3]. The challenge with low dose imaging is the degradation of image quality with poor spatial resolution. Even with accurate acquisition settings, set during screening process the presence of noise is observed, which is mainly due to low dose imaging protocol. Some of the low dose imaging protocol suggests to acquire the projection data at a sparse angle leading to under-sampling due to lesser radiation dose, and then apply suitable compensating reconstruction algorithm to get better quality images (on par with standard dose) that compensates the under-sampling.

From the literature and official websites of leading CT unit developers, we observe various compensating algorithms which are intended to address poor spatial resolution in CT images which are acquired by following low dose imaging protocol. Most predominantly used methods are Adaptive Statistical Iterative Reconstruction (ASIR), Iterative Reconstruction in Image Space (IRIS) and Model Based Iterative Reconstruction (MBIR) [4]. In case of IRIS, the de-noising property of iterative function helps to achieve a 50 % reduction in radiation dose [5]. In case of MBIR, number of samples, allowing multiple projections of the same object allows construction of CT image with better image quality and improved spatial resolution [1, 6]. Iterative algorithm is reported to construct image with better quality even with incomplete data, preserving higher spatial resolution of the CT images [2]. Comparison of various techniques is shown in the Table 1. Highly Constrained Back Projection (HYPR) was introduced recently for the reconstruction of under sampled (sparse view angle) CT/MRI (Magnetic Resonance Imaging) images [7]. In any given clinical case, both temporal and spatial resolution is of clinical interest as they provide definite and clear anatomical structures. To have better spatial resolution the acquisition need to be complete in all respect while, to achieve higher temporal resolution acquisition system should be tuned to acquire projections in lesser time, but, there is a trade-off between acquisition time and quality of constructed image. To address this trade-off one possible approach is to scan the object with a sparse view (achieving lesser acquisition time). And later apply compensating algorithms as aforementioned to achieve improved image quality. The HYPR method works on this principle.

Table 1 Comparison of various reconstruction techniques

Reconstruction techniques	Disadvantages	Advantages
ASIR	Computation time is higher (approximately 30 % higher for a standard CT) and artificial over-smoothing of the image	Allow significant radiation dose reduction
IRIS	Very high computational cost, which can be 100–1000 times higher than filtered back projection (FBP)	Permit the detection process to be accurately modelled
MBIR	Complicated algorithm, uses multiple iterations and multiple models. The reconstruction time is very high	Significant dose reduction
HYPR	Poor spatial resolution for dynamic low dose CT images	Better computation time

2 Existing Image Reconstruction Techniques

2.1 Adaptive Statistical Iterative Reconstruction (ASIR)

GE Healthcare has introduced new CT unit called BrightSpeed Elite© with the feature of low dose imaging. Internally Adaptive Statistical Iterative Reconstruction (ASIR) algorithm works for this feature [8]. Due to the low dose imaging feature, images are captured with reduced tube current. The ASIR technique uses Filtered Back Projection (FBP) constructed standard image as the primary building block [9, 10].

2.2 Iterative Reconstruction in Image Space (IRIS)

Siemens has introduced new CT modality called SAFIRE© to enable low dose imaging, which works on the principle of Iterative Reconstruction in Image Space (IRIS) [11]. Basically, IRIS uses both data pertaining to sinogram space and image space. The number of iterations is dependent on the requirement of a specific scan. This technique is recorded to provide higher Contrast Noise Ratio (CNR) and Signal-to-Noise Ratio (SNR) in low dose imaging as well as some exceptional clinical cases such as paediatric and obese patients [12].

2.3 Model Based Iterative Reconstruction (MBIR)

MBIR improves the image quality, which are generated by low dose imaging protocol. Comparatively, MBIR significantly removes the image noise and artifacts over ASIR technique [13].

3 Proposed Image Reconstruction Technique (HYPR)

In HYPR method all the time slices are subjected to constrained forward and backward projections. The composite image is generated by integrating all the images of previous results. The resulting composite image exhibits good spatial characteristics. However, the composite image exhibits poor temporal characteristics. Hence a weight image is generated by calculating the ratio of unfiltered back projections of original projections to the unfiltered back projection of the composite image. The good temporal resolution is expected in weight image as it considers both original images and composite images. When weight image is multiplied with composite image, the result is a HYPR frame with good signal to noise ratio (SNR) and good temporal characteristics. Figure 1 presents the system model of HYPR. Original HYPR calculates composite image and weight factor and try to address spatial resolution improvement. The projection S_t is obtained by applying radon transform R on the image I_t at some angle ϕ_t

$$S_t = R_{\phi_t}[I_t] \tag{1}$$

Next, the composite image C is found from the filtered back projection applied to all the S_t is as follows:

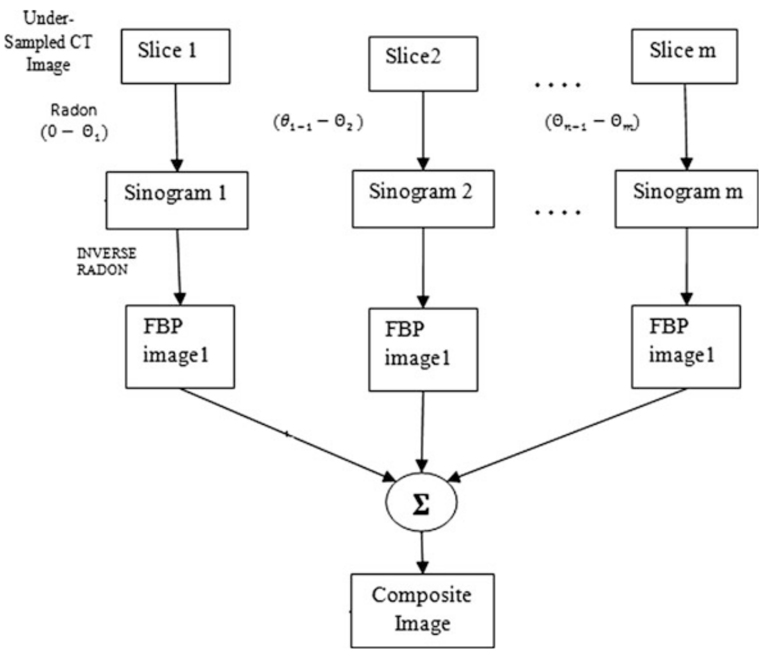

Fig. 1 System model of highly constrained back projection (HYPR)

$$C = \sum_{i=1}^{N} R_{\phi_{t_i}}^{f} [S_{t_i}] \tag{2}$$

3.1 Quality Evaluation Parameter: Peak Signal-to-Noise Ratio (PSNR)

In medical imaging, the quality of reconstructed images is subjective in nature. They are accepted to provide clear and distinct visualization of anatomical structures. However, to access the proposed HYPR method of quantifying the image quality we preferred to choose Peak Signal-to-Noise Ratio (PSNR). It provides the presence of the signal component against the unwanted noise component. In usual practice, we calculate PSNR by Mean Square Error (MSE) and represent using decibel unit. Normally, CT images with PSNR value greater than 40 dB are considered to be clinically useful, while images with lesser than 20 dB are of no much use. If K is the noisy approximation of noise-free $m * n$ monochrome image I, then MSE can be defined as [14, 15]:

$$MSE = \frac{1}{xy} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i,j) - K(i,j)]^2 \tag{3}$$

The PSNR is defined as:

$$PSNR = 10 \cdot \log\left(\frac{255}{\sqrt{MSE}}\right) \tag{4}$$

4 Results and Discussions

We have considered a MATLAB platform for simulation purpose. The experimental setup consists of different CTA (Computed tomography Angiography) datasets collected from online database and then classified based number of time frames, intensity variation, dynamic nature and noise level. For the study purpose, we have considered the original image as shown in the Fig. 2 and have obtained the under-sampled images by varying the incremental angle of 1.5°, 2°, 4°, 8° as shown in the Fig. 2b–e. Composite image of the original dataset is obtained by initially applying radon and radon filter back projections and summation of all original images at a sparse angle (Shown in Fig. 3a).

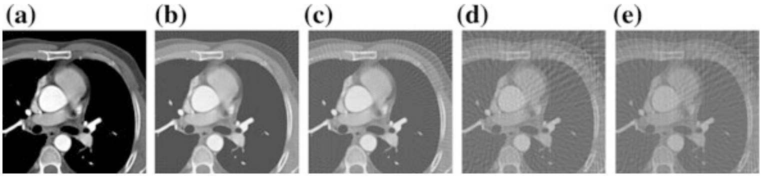

Fig. 2 **a** Original standard dose image, **b** undersampled image with an incremental angle 1.5°, **c** undersampled image with an incremental angle 2°, **d** undersampled image with an incremental angle 4°, **e** Undersampled image with an incremental angle 8°

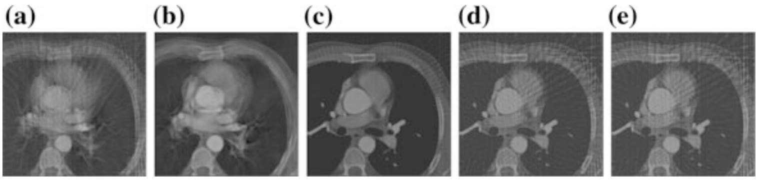

Fig. 3 **a** Composite image of the original image, **b** composite image with an incremental angle 1.5°, **c** composite image with an incremental angle 2°, **d** composite image with an incremental angle 4°, **e** composite image with an incremental angle 8°

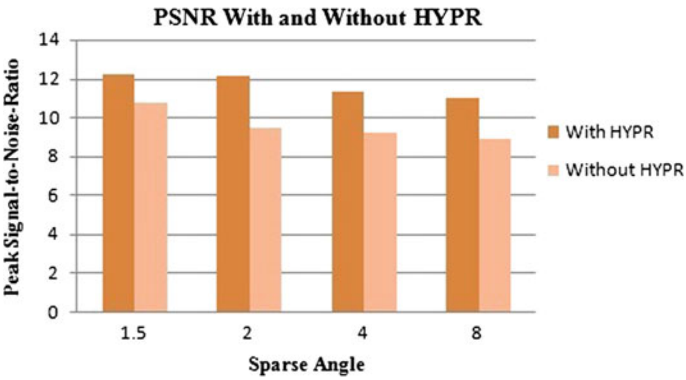

Fig. 4 PSNR (with and without HYPR) at various sparse angles

Incremental Angle datasets are then subjected to radon and iradon filter-back projection and summation of all the images are performed to obtain a composite image. Composite images obtained by varying the incremental angle of 1.5°, 2°, 4°, 8° are as shown in the Fig. 3b–e.

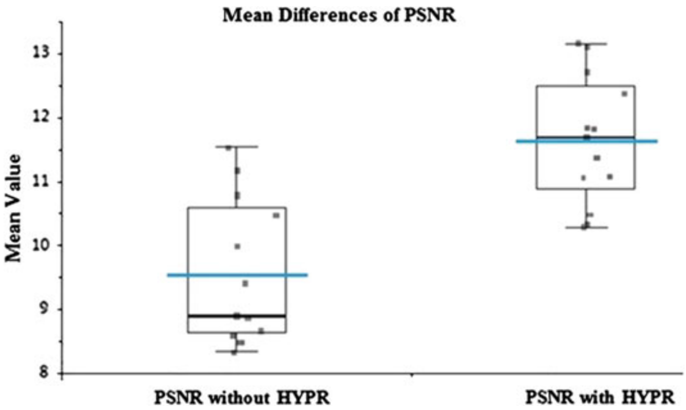

Fig. 5 Mean differences of PSNR (with and without HYPR)

5 Conclusion

Comparative study of the dataset using standard dose (without HYPR) and low dose (with HYPR) by considering the sparse, angular projections are made and the quality evaluation parameter, PSNR is calculated. From the Fig. 4 it is clear that the quality of the images that were not acceptable with the PSNR below 10 dB, was enhanced significantly when HYPR was applied and it also shows the extent to which low dose is achievable without compromising the image quality. The mean difference of PSNR with HYPR and without HYPR is depicted in the Fig. 5 conducted for thirteen experiments shows a significant improvement in the PSNR value. An increase in the PSNR value will eventually lead to the increase in the spatial resolution of the images. Hence, we were able to assess the spatial resolution of the images obtained using the low dose.

References

1. Brenner, D.J., Hall, E.J.: Computed tomography -an increasing source of radiation exposure. N. Engl. J. Med. **357**(22), 2277–2284 (2007)
2. Tubiana, M., Nagataki, S., Feinendegen, L.E.: Computed tomography and radiation exposure. N. Engl. J. Med. **358**(8), 850 (2008)
3. Entrikin, D.W., Leipsic, J.A., Carr, J.J.: Optimization of radiation dose reduction in cardiac computed tomographic angiography. Cardiol. Rev. **19**(4), 163–176 (2011)
4. European Society of Radiology (ESR): ECR 2012 Book of Abstracts-B-Scientific Sessions. Insights into imaging **3**(Suppl 1), 135 (2012)
5. Friedland, G.W., Thurber, B.D.: The birth of CT. AJR Am. J. Roentgenol. **167**(6), 1365–1370 (1996)

6. de Gonzalez, A.B., Mahesh, M., Kim, K.P., Bhargavan, M., Lewis, R., Mettler, F., Land, C.: Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch. Intern. Med. **169**(22), 2071–2077 (2009)
7. O'Halloran, R.L., Wen, Z., Holmes, J.H., Fain, S.B.: Iterative projection reconstruction of time-resolved images using highly-constrained back-projection (HYPR). Magn. Reson. Med. **59**(1), 132–139 (2008)
8. Lee, T.Y., Chhem, R.K.: Impact of new technologies on dose reduction in CT. Eur. J. Radiol. **76**(1), 28–35 (2010)
9. Silva, A.C., Lawder, H.J., Hara, A., Kujak, J., Pavlicek, W.: Innovations in CT dose reduction strategy: application of the adaptive statistical iterative reconstruction algorithm. Am. J. Roentgenol. **194**(1), 191–199 (2010)
10. Leipsic, J., Heilbron, B.G., Hague, C.: Iterative reconstruction for coronary CT angiography: finding its way. Int. J. Cardiovasc. Imag. **28**(3), 613–620 (2012)
11. Hur, S., Lee, J.M., Kim, S.J., Park, J.H., Han, J.K., Choi, B.I.: 80-kVp CT using iterative reconstruction in image space algorithm for the detection of hypervascular hepatocellular carcinoma: phantom and initial clinical experience. Korean J. Radiol. **13**(2), 152–164 (2012)
12. Grant, K., Raupach, R.: SAFIRE: Sinogram affirmed iterative reconstruction. siemens medical solutions whitepaper. http://www.medical.siemens.com/siemens/en_US/gg_ct_FBAs/files/Definition_AS/Safire.pdf. Accessed Nov 2012
13. Dutta, J., Ahn, S., Li, Q.: Quantitative statistical methods for image quality assessment. Theranostics, **3**(10), 741 (2013)
14. Peak Signal to Noise Ratio: http://en.wikipedia.org/wiki/Peak_signal-to-noise_ratio
15. Gupta, S., Dua, M.: A hybrid approach for dehazing images. Int. J. Hybrid Inform. Technol. **7**(3) (2014)