Adaptive Noise Reduction and Sharpening of OSEM-Reconstructed Data

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***Abstract*—The Pixon[1] method, a statistically rigorous procedure for adaptive noise suppression that avoids the generation of spurious artifacts yet preserves all the statistically justifiable image features resident in the raw counts, is applied to nuclear studies. The present work focuses on adaptive postsmoothing and sharpening of OSEM-reconstructed data at various count levels, with the ultimate goals to (i) increase sensitivity for detection of lesions of small size and/or of small activity-to-background ratio, (ii) reduce data acquisition time, and (iii) reduce patient dose. We use simulated and measured data and human-observer studies, which are analyzed using quantitative measures. Conclusion: The detectability shows improvement, as does resolution, especially at low counts. Clinical trials would be required to assess this method of image postprocessing.**

I. Introduction

The unique Pixon[1] method for the suppression of random noise in images, initially developed for astronomical applications [1–3], is adapted and applied to nuclear medical imaging. The method is a statistically rigorous procedure for noise suppression that avoids the generation of spurious artifacts yet preserves all the statistically justifiable image features resident in the raw counts. The method optimizes noise suppression by taking full advantage of the local information content of the image and avoiding global noise-suppression criteria [4–7], which may not be locally optimal. Pixon processing is therefore especially well suited to imaging at low signal-to-noise ratio and is particularly attractive for applications in nuclear medicine [8–9]. The present work focuses on adaptively postsmoothing and sharpening OSEM-reconstructed data, where each slice is postprocessed independently. The preprocessing case is treated in paper M07-233 (MIC2005).

The postprocessing procedure is ad hoc, because the method assumes that the reconstructed voxel counts are independently Poisson distributed, while in reality they are correlated and do not follow an exact Poisson distribution. Nevertheless, we seek to investigate the resulting reconstruction, with the ultimate goals to (i) increase sensitivity for detection of lesions of small size or of low contrast, (ii) reduce data acquisition time, and (iii) reduce patient dose. We use both simulated and measured phantom data at various count levels. The objects are cylindrical phantoms with sphere or rod inserts, reconstructed with OSEM Flash3D[2] with 3D collimator blur compensation, CT attenuation correction and scatter compensation.

II. Methods

The key objective of the Pixon method is to generate an output image that is as smooth as possible yet statistically consistent with the raw counts, given the noise and image formation model. The method is a spatially adaptive smoothing algorithm, in which the width of the smoothing kernel at each image location is adjusted to the local image conditions without making any parametric assumptions about the image [1–3,8]. Where the underlying image is uniform, or the signal-to-noise ratio is not high, it is possible to smooth over a wider span of pixels without loss of information; where the underlying image varies significantly relative to the noise, the smoothing kernel is restricted to fewer pixels to avoid loss of resolution. The local information content of the image determines the best smoothing.

As an example of the planar denoising ability, Fig. 1 shows planar acquisitions of the rod phantom at varying counts processed with the Pixon method [9]. The remarkable ability to extract the rod structure from the very noisy 100 kc image is clearly demonstrated.

Noiseless simulated projections are generated using a ray-tracing method, from which 10 Poisson realizations at varying count levels [1.7, 2.9, 5*n, n=1...8. units: kc/view] are generated. This simulates the acquisition of Data Spectrum's Cylinder with the 6 spheres (0.5 – 16 ml) at a 5:1 concentration ratio in a 128x128 matrix with 4.8 mm pixels, and 60 views over a 180-degree arc at 25 cm. The data are

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Manuscript received Nov. 11, 2005

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[1] Pixon® is a registered trademark of Pixon LLC.

[2] Flash3D is the OSEM iterative reconstruction with collimator blur modeling in the transverse and axial directions of Siemens Medical Solutions USA, Inc., Molecular Imaging.

reconstructed with Flash3D using no attenuation, scatter and collimator compensation, postsmoothed with a 3D Gaussian of 2 pixels FWHM. This is followed by Pixon processing of the reconstruction, in which each slice is adaptively denoised and deconvolved with a 2D Gaussian of 2 pixel FWHM. The Pixon noise-reduction (smoothness) parameter [8] is set to dn=1.5 [9]. Note that this procedure is rather ad hoc, because it does not account for the true noise model in the reconstructed data, in which voxel counts are correlated and do not follow an exact Poisson distribution. Nevertheless, the question arises if such an approach has benefits, and this is what this study seeks to determine. Real data are acquired on a Symbia TruePoint SPECT·CT using Data Spectrum's Cylinder loaded with ^{99m}Tc, using the rod and sphere inserts (peak window center: 140keV with a width of 15%, 3.3 mm pixel, 128^2-matrix, 25 cm rotation radius). The acquisitions are stopped on counts (250kc/view) and binomially subsampled to obtain any count level between 0 and 250 kc/view. A corresponding attenuation map is derived from a CT scan for attenuation correction.

We investigate the effects of noise suppression on the reconstruction. One of the quantitative measures is an SNR measure, the detectability index DI, defined as the difference between the average counts per voxel in the spheres (S) and the background (B) ROI, normalized by the noise in the background (N): $DI = (\langle S \rangle - \langle B \rangle)/\langle N \rangle$, where the angular brackets indicate averaging over voxels in the ROI and all realizations. DI increases if the noise in the image is reduced and signal preserved. Besides DI and a quantitative resolution analysis, we use a human-observer detection task study to assess the performance differences between Flash3D reconstructions and adaptively postprocessed reconstructions. For this, 10 readers are asked to identify the presence of a sphere of unknown size and location. They are, however, instructed that the image contains either one sphere or no sphere. Each reader has a set of 60 images half of which are placebo (from slices that do not intersect any sphere). The 30 cases correspond to 10 noise levels and 3 sphere volumes (0.5 ml, 1 ml, or 2 ml), processed as described above. The reader is simply asked whether or not s/he detects a sphere anywhere in the image, and the response is recorded automatically together with the decision time. The reader is allowed to change the windowing parameters (upper and lower cutoffs and the gamma parameter of the gray scale images). This freedom is chosen to simulate clinical reality.

III. RESULTS

The results are shown in Fig. 2–8; we skip a detailed description of the results due to space constraints.

IV. DISCUSSION

This project attempts to investigate the effect of adaptive smoothing and sharpening of reconstructed data, OSEM-reconstructed with 3D collimator response modeling and optional attenuation and scatter compensation, followed by 3D Gaussian smoothing with 2 pixels FWHM. The Pixon method is then used to sharpen each reconstructed slice by a 2D Gaussian of 2 pixels FWHM and to adaptively smooth the image. Unlike the preprocessing case (M07-233) the projection data remain unchanged to avoid the pitfall of suppressing tomographic information prior to the reconstruction.

The question is whether adaptive postsmoothing improves the perceived image quality, especially at low count data, and can also mitigate the usual loss of resolution in the reconstruction. The procedure used here is rather ad hoc, as the Pixon method assumes independent Poisson noise in each voxel, while OSEM-reconstructed data have correlated noise, which is not exactly Poisson distributed. Nonetheless, the spatially adaptive Pixon method may be able to suppress noise and even improve resolution with deconvolution.

It turns out that the ability to detect lesions may be improved. Fig. 1–2 show the DI increasing roughly 2–3 fold over standard reconstruction. On the other hand, the human-observer study does not indicate a much better ability to detect lesions (Fig. 3). The false positive fraction is around 20% at all count levels, indicating that the placebos are identified as such rather well, which makes an ROC interpretation very difficult. If the method is applied to clinical and phantom data (Fig. 4–7), the image quality in general seems improved, especially for data at reduced counts (examples here are 25% and 50%). There is only minor resolution loss for the two adjacent lesions in the bone study (Fig. 4), and cold and hot sections of the rod phantom can be seen (Fig. 6–7). In particular, the cold rods sections at reduced counts using the adaptive post smoothing are still clearly visible, unlike in the "preprocessing" study (MIC07-233).

V. CONCLUSIONS

Given the rather ad hoc method of adaptively postsmoothing the Flash3D reconstructed data using the Pixon method (which assumes that the voxel counts are uncorrelated and Poisson distributed) the results are surprisingly good. The detectability shows improvement, and the usual loss of resolution, especially at low counts, is diminished. The clinical and phantom data also show improved image quality. The postsmoothing may need to be better adapted to the noise structure of OSEM, but to investigate this topic is outside the scope of this study. In any case, clinical trials would be required to assess this method of image postprocessing. The ad hoc method presented in this study also shows promising results when applied to reduced counts due to lower acquisition time or dose, and warrants further investigation.

VI. REFERENCES

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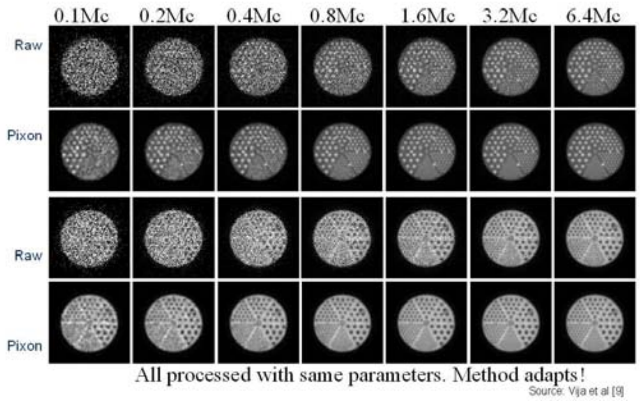
VII. ACKNOWLEDGMENT

The authors would like to thank the observer study participants at Siemens Molecular Imaging.

VIII. FIGURES



All processed with same parameters. Method adapts!

Source: Vija et al [9]

Fig. 1: Raw and Pixon processed planar images of hot and cold sections of the rod phantom acquired to range of total counts between 100 kc and 6400 kc. Once the denoising parameter is adjusted to dn=1.75 according to the CDF result no further change in the processing parameters is needed [9].

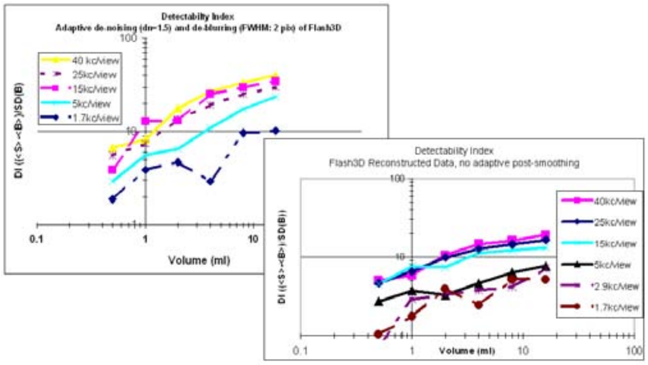


Fig. 2: Detectability index for all spheres at the various counts with and without postprocessing.

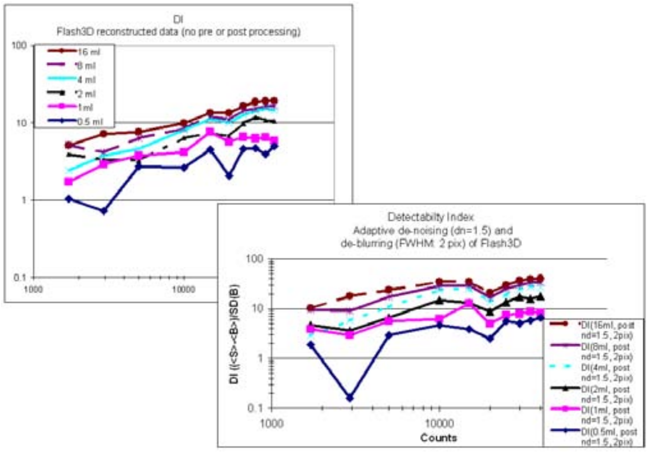


Fig. 3: Detectability index for all spheres at the various counts with and without postprocessing.

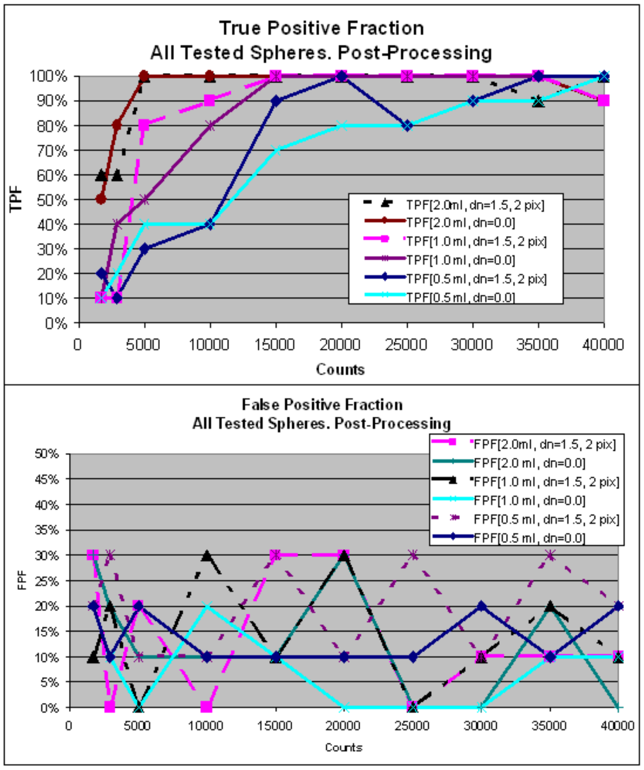


Fig. 4: True and False Positive Fraction (TPF, FPF) for varying spheres at the various counts. Note1: TPF essentially increases as counts increase. Note2: FPF is essentially constant.

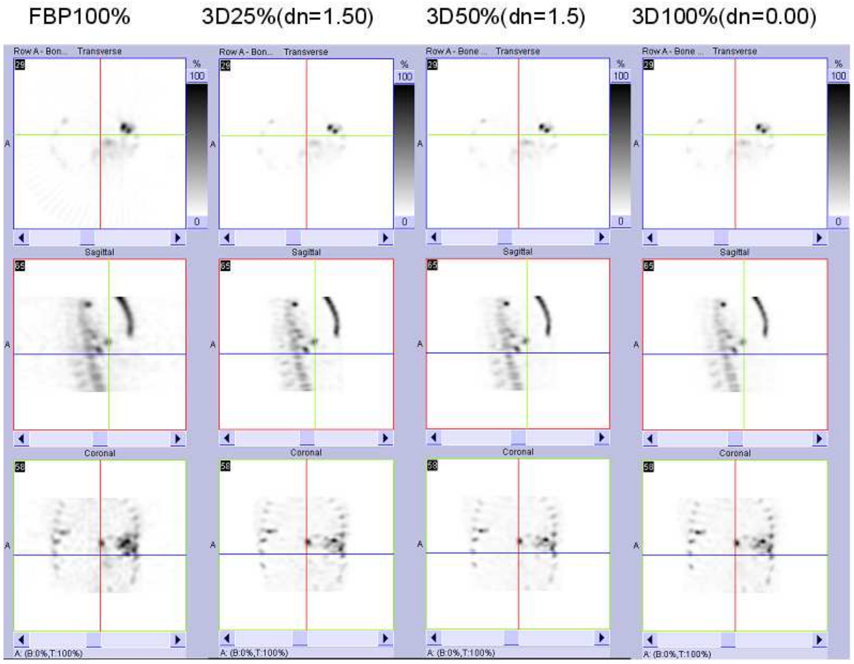


Fig. 5: Bone study at 100% and 50% subsampled counts without and with adaptive post-processing. The columns from left to right show FBP at 100%, Flash3D at 25%, and 50% of counts with post-processing and Flash3D at 100% of counts without any post-processing. Almost no loss of resolution is seen when counts are reduced and adaptive denoising and sharpening is performed.

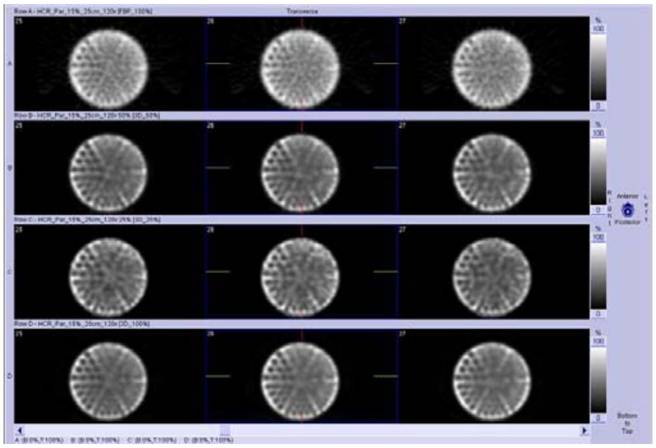


Fig. 6: No post smoothing after FBP and Flash3D reconstruction (effect on cold lesions).

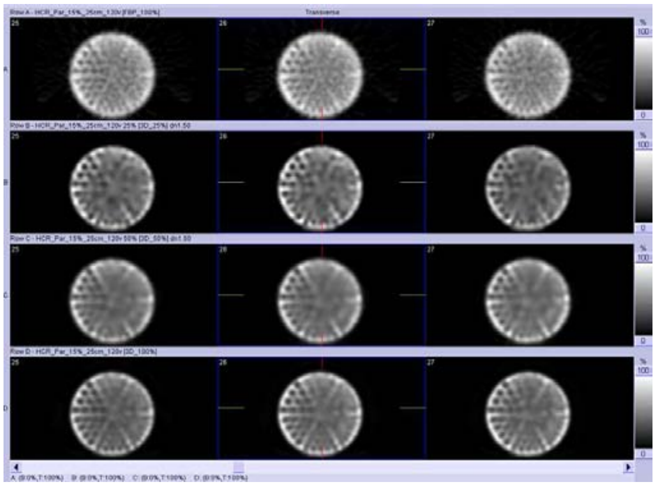


Fig. 7: Adaptive post smoothing Flash3D reconstruction at 50% and 25% of total counts (effect on cold lesions).

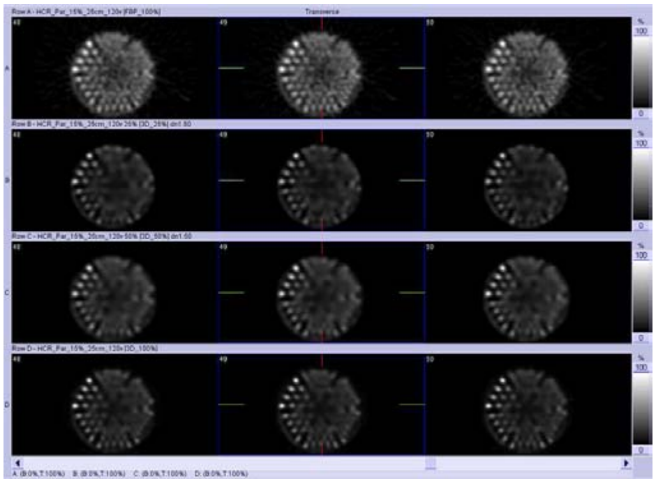


Fig. 8: Adaptive post smoothing Flash3D reconstruction at 50% and 25% of total counts (effect on hot lesions).