Developing real-space filtering techniques for image enhancement in computed tomography reconstruction

Michael Williams*[1], Stephen Bosi †[1,2], Konstantin Pavlov‡[1, 3, 4]

[1]School of Science and Technology, University of New England, Australia
[2]Institute of Medical Physics, University of Sydney, Australia
[3]School of Physics and Chemical sciences, University of Canterbury, New Zealand
[4]School of Physics and Astronomy, Monash University, VIC, Australia

Keywords: X-ray tomography, tomographic image reconstruction, real-space image enhancement.

Summary: Selective enhancement algorithms seek to identify intensity spikes (associated with Poisson noise) and boundaries (edges, corresponding to real features of a scanned object) within projections (for computed tomography) and preferentially enhance boundaries. Improved image quality (and image-quality metrics) are observed for CT reconstructions from selectively enhanced projections.

1. INTRODUCTION

Cone-beam CT using 2D flat-panel detectors is finding increasing application in medical imaging, image guidance etc. However, 2D detectors are more susceptible to noise from scattering radiation than detectors used in more traditional fan-beam CT [1]. Feldkamp-Davis-Kress (FDK) filtered back-projection [2] is one of the most efficient and most commonly used reconstruction algorithms [3, 4]. Part of the algorithm involves adjusting amplitudes of different image spatial frequency components by applying a suitable filter in Fourier space (Fourier-filter or “kernel”).

Typically, clinical CT systems deal with image noise by modifying the Fourier-filter response to adjust the attenuation or enhancement of different frequency components in the image. This choice is a compromise between minimising image noise and maximising contrast of tissue boundaries, as attenuating high frequencies reduces the contrast of both noise and sharp boundaries.

2. EXPERIMENTAL METHOD

Three sets of images, from CT projections (of the Varian skull-phantom), were utilised for testing: the unaltered projections sampled as 16-bit images; the projections, re-scaled to 14-bit and seeded with Poisson noise; the projections, scaled to 12-bit and seeded with Poisson noise. Seeding with Poisson noise was to simulate CT projections taken at lower X-ray intensity.

CT projections were smoothed, under a standard median filter. Median filtration was used for its utility in smoothing random (discrete) spikes within an image [5], although, high-frequency edge features may also be smoothed [6]. Subtraction of the median-filtered CT projection (from the original projection) yields a map of smoothed features (inclusive of noise and high-frequency real-features).

Pixel-wise division of this high-frequency feature map by the square-root of the median-smoothed projection yields a modified high-frequency feature map. Addition of this modified high-frequency feature map to either the original (or median-filtered) projection preferentially enhanced boundary features within the projection (over noise).

*e-mail: mwilli34@myune.edu.au
†e-mail: stephen.bosi@une.edu.au
‡e-mail: konstantin.pavlov@canterbury.ac.nz

OSCaR (the open-source cone-beam CT reconstruction tool for imaging research) [7] was used to reconstruct from projections (both enhanced and not). Reconstructions from enhanced projections were compared with reconstructions from those not enhanced.

Qualitative assessment of image quality (visual inspection) and quantitative assessment of image quality were used to analyse results. Computation of: signal-to-noise ratio (SNR); contrast-to-noise ratio (CNR) of the CT reconstructions; peak signal-to-noise ratio (PSNR) and contrast-improvement-ratio (CIR) provided quantitative measures on image-quality. PSNR provided a relative measure of the total amount of noise within a CT reconstruction, whilst CIR quantified how much the contrast (over the entire CT reconstruction) had changed from the contrast of a reference image (provided by reconstructions from those projections not enhanced). A CIR of zero indicates no change in contrast, a CIR of 1 indicates a contrast change of 100%.

3. RESULTS

Application of the described high-frequency feature maps in enhancement of CT projections prior to reconstruction via FDK filtered backprojection yielded improvements in quality of CT reconstructions (see Fig.1). Applying enhancement to previously median-smoothed was seen to yield the best outcomes. Comparing CT reconstructions and image-quality metrics, the relative benefits of selective enhancement (prior to reconstruction) were more strongly-pronounced from projections seeded with Poisson noise. For reference, the PSNR for reconstruction from the unaltered Varian projections (no added noise) was 62.32.

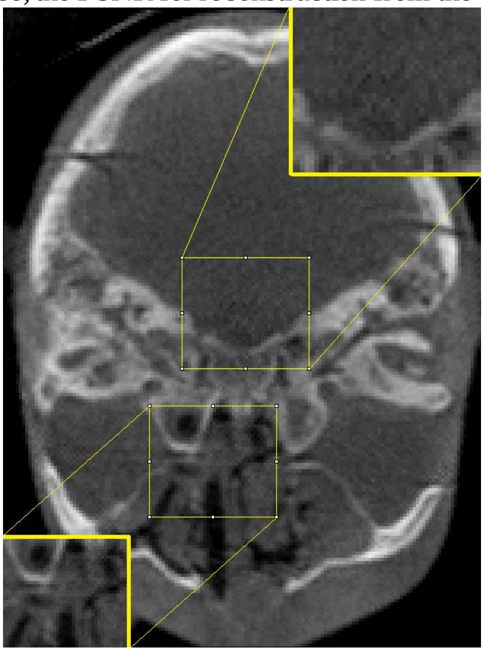

Figure 1a Reconstruction for enhanced Varian skull-phantom, seeded with noise (12-bit). (PSNR = 61.80, CIR = 0.23)

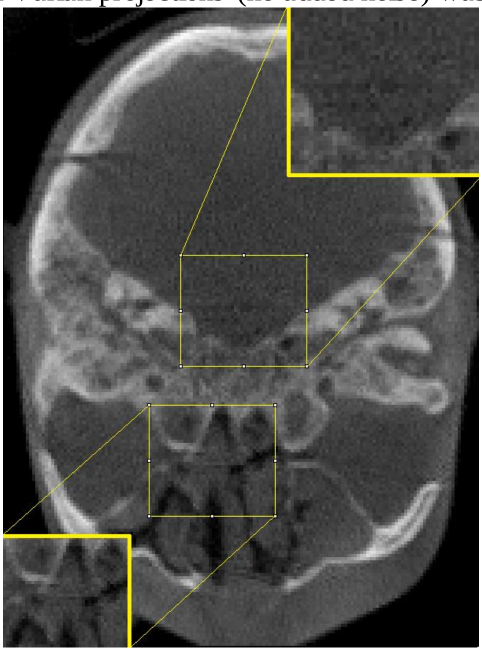

Figure 1b Reconstruction for Varian skull-phantom (no enhancement), seeded with noise (12-bit). (PSNR = 61.13)

References

1. Pan, X., et al., *Anniversary Paper: Development of x-ray computed tomography: The role of Medical Physics and AAPM from the 1970s to present.* Medical Physics, 2008. **35**(8): p. 3728-3739.
2. Feldkamp, L.A., L.C. Davis, and J.W. Kress, *Practical cone-beam algorithm.* Journal of the Optical Society of America A, 1984. **1**(6): p. 612-619.
3. Wang, G., H. Yu, and B. De Man, *An outlook on x-ray CT research and development.* Medical Physics, 2008. **35**(3): p. 1051-1064.
4. Hsieh, J., et al., *Recent Advances in CT Image Reconstruction.* Current Radiology Reports, 2013. **1**(1): p. 39-51.
5. McAndrew, A., *An Introduction to Digital Image Processing With Matlab.* 2004: Course Technology Press.
6. Dong, Y., R.H. Chan, and S. Xu, *A Detection Statistic for Random-Valued Impulse Noise.* IEEE Transactions on Image Processing, 2007. **16**(4): p. 1112-1120.
7. Rezvani, N., et al., *OSCaR: An Open-Source Cone-Beam CT Reconstruction Tool for Imaging Research.* Medical Physics, 2007. **34**(6Part2): p. 2341-2341.