3D Tomography - Increased Accuracy and One to Two Orders of Magnitude Accelerated Reconstruction with eHECTOR - the New Extended High Efficiency Computed Tomography with Optimized Recursions

Wolfram Rudolf Jarisch[1], William Harris Solomon[2]

[1] Cyber Technology, Inc., Potomac, MD, U.S.A.
[2] Satsyil Corp., Herndon, VA, U.S.A.

A novel analytic-based extended High Efficiency Computed Tomography (CT) with Optimized Recursions (eHECTOR) method provides increased accuracy and a high-dimensional rate of convergence of nonlinear iterative CT reconstruction compared to traditional iterative reconstruction (IR) methods [1]. Traditional IR is initialized with analytic-based linear Filtered Back-Projection (FBP) or Fast Fourier Transform (FFT) methods [2,3]. The absence of analytic approximations to perform subsequent iterations requires computationally expensive iterative numerical methods (INM) such as SART to refine and constrain the initial density estimate [4]. INM methods reduce radiation exposure and provide better use of measurement data at the expense of over two orders of magnitude slower speed than linear methods.

Here we compare the performance of eHECTOR with ordered subset SART (OS SART) [7] when computing resources are limited as in very large reconstruction problems. eHECTOR further regularizes concepts in HECTOR and HECT [5,6] by combining non-linear data transformations and pixel and voxel related relaxation factors.

This simulation demonstrates high accuracy and a 79-fold increase in speed of eHECTOR resulting from the use of a dynamic relaxation matrix, non-linear transformations, robust estimation [8], and analytic results applied to linearized density state updates within the non-linear estimation process. Based on robust state updates, the highly contractive mapping (CM) of linear inversion methods becomes active and operates effectively on small residual errors. The effectiveness of CM is achieved through a combination of several innovations:

1. given monotone nonlinear data transformations, efficiently evaluate relaxation parameters from inverse function slopes of data transform;
2. start the reconstruction with a single voxel representing the entire volume and single pixels representing individual projection densities;
3. initially, iterate density estimates with robust estimation at any given resolution until small signal update approximations are valid and efficient;
4. use a linear inversion method such as FBP or FFT to process signal updates;
5. sub-divide densities into representations with higher resolution when small signal approximations are satisfied and sufficient convergence has been achieved;
6. program terminates when projection residual errors are dominated by measurement noise and show minimal traces of the object of interest.

The dominant computing effort in eHECTOR is the final full resolution reconstruction due to the geometric expansion of the resolution. The need for additional full resolution iterations depends on factors such as the contrast properties of the object of interest.

The eHECTOR method solves several longstanding problems of tomographic reconstruction by: (i) replacing the traditional relaxation parameter with two large sets of parameters, typically in the order of 10^8 elements; each relaxation parameter is associated with individual pixel or voxel density gain adjustments; (ii) gradually increasing the resolution efficiently supporting small signal approximations; and (iii) concentrating the dominant computing effort in the final full resolution reconstruction. For performance comparison all sub-systems components in Figures 1 and 2 for eHECTOR and OS SART were computed using [7] on the medium performance NVIDIA Quadro P4000 graphics card with 1792 CUDA cores on a unit peak-density phantom.

References:

[1] W Jarisch, U.S. Patent Application No. 15/816,745, Nov. 2017.
[2] B De Man, S Basu, et al., J Hsieh, K Sauer, IEEE Nuc. Sci. Symp. Conf. Rec. M11-339, 2005.
[3] Y Zhang-O'Connor , J A Fessler, IEEE Trans. Medical Imag., vol. 25, no. 5, May 2006.
[4] H Nien, J A Fessler, Rad. and Nuc. Med., pp. 260-3, 2015.
[5] W Jarisch, Microscopy and Microan. Conf., Portland, OR, Aug., Late Breaking Poster LB15, 2010.
[6] W Jarisch, A C Dohnalkova, Microscopy and Microanalysis Conf., Richmond, VA, July, 2009.
[7] A Biguri, et al., Biomedical Physics & Engineering Express, Volume 2, Number 5, September 2016.
[8] P J Huber, Robust Statistics, John Wiley, New York, 1981.

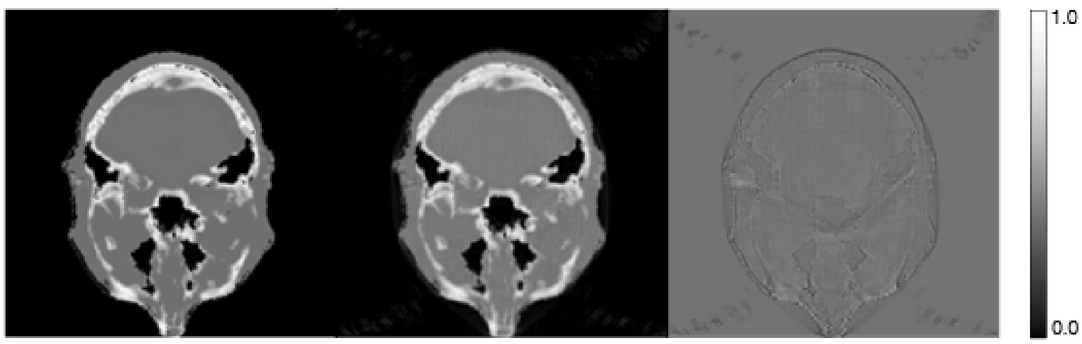

Figure 1. eHECTOR analytic approach to reconstruction [1]: slices through head phantom: left: slice through phantom; middle: slice through reconstruction; right: slice of residuals. Observe significantly reduced residuals compared to SART. Reconstruction 132.6 sec, RMS error 0.000363, 400 projections.

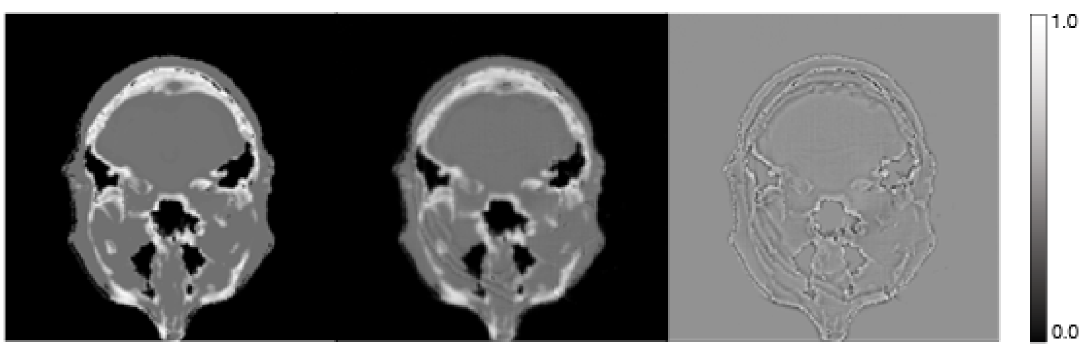

Figure 2. OS SART numerical approach to reconstruction [7]: slices through head phantom: left: slice through phantom; middle: slice through reconstruction; right: slice of residuals. Reconstruction 10,540 sec, RMS error 0.000530, 400 projections. Note the 79-fold increase in computing time.