**Background Information**

**By Ge Wang and Hengyong Yu**

**Why ARC –** In the Sub-mSv CT imaging U01 meeting at NIBIB/NIH on July 21, 2015, each of the funded U01 teams began with 45-minute summary of their approach, results and plan. This was followed by frank discussions of challenges occurred in the past year, problems perceived by the peers, ideas for moving forward, and brainstorming about potential areas of collaboration. In this meeting, a strong interest was expressed in an open-source software for analytic cone-beam image reconstruction, along with the hope that our team will offer this service. Being motivated by the need and trust, here we present this website in a primitive form, and will upgrade it in the future.

**Analytic Reconstruction –** Multi-slice/cone-beam CT image reconstruction has been a research focus over the past two decades, especially in the spiral/helical scanning mode with a closed form solution. Currently, CT scanners primarily use analytic algorithms, while iterative solutions are under testing and manufacturer-specific. To allow comparison of new CT image reconstruction algorithms with mainstream methods, representative analytic algorithms are important as the benchmark.

**Representative Algorithms –** The development of analytic algorithms for spiral cone-beam CT may be divided into the following four stages: (1) approximate reconstruction (1991–present), (2) exact reconstruction with multiple turns (1995–2001), (3) exact reconstruction based on PI (π) lines (2002–2004) and (4) general exact reconstruction (2004–present). For further details, please read relevant review papers, such as Wang G, Ye Y, Yu HY: Approximate and exact cone-beam reconstruction with standard and non-standard spiral scanning. Phys. Bio. & Med. 52:R1-R13, 2007. Among published algorithms, we have prepared three well-known algorithms that were published in 1991, 2004 and 2006 respectively.

**Algorithm 1991 –** The first is the original spiral cone-beam/multi-slice algorithm fully described in Wang G, Lin TH, Cheng PC, Shinozaki DM: A general cone-beam reconstruction algorithm. IEEE Trans. Med. Imaging 12:486-496, 1993 (Originally published in Wang, G., T. H. Lin, P. C. Cheng, D. M. Shinozaki and H. Kim (1991). SPIE Proceedings 1556:99-112).

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| *(a) (b)* |
| S*piral cone-beam/multi-slice image reconstruction. (a) The initial system prototyped based on an x-ray shadow projection microscope for evaluation of rod-shaped material samples, and (b) the imaging geometry for spiral cone-beam/multi-slice image reconstruction (from Wang G, Lin TH, Cheng PC, Shinozaki DM: A general cone-beam reconstruction algorithm. IEEE Trans. Med. Imaging 12:486-496, 1993; and also a half-scan version in Wang G, Liu Y, Lin TH, Cheng PC, Shinozaki DM: Half-scan cone-beam X-ray microtomography formula. Journal of Scanning Microscopy 16:216-220, 1994).* |

This algorithm is computationally efficient because of its filtered backprojection structure. The key step is a cosine correction for each of rays in a cone-beam geometry. Although the first spiral cone-beam algorithm was heuristically derived, like Feldkamp’s algorithm, it has several desirable exact reconstruction properties. Assume that the reconstruction is performed from projection data collected from a turn of a scanning locus, we have proved that the reconstruction is theoretically exact on the mid-plane, of a point object, or if an object is longitudinally homogeneous. These properties further justify the algorithm.

**Algorithm 2004 –** The second is the theoretically exact spiral cone-beam multi-slice algorithm derived by Katsevich (Katsevich A: An improved exact filtered backprojection algorithm for spiral computed tomography. Advances in Applied Mathematics 32:681–697, 2004), as implemented by Yu and Wang (Yu HY, Wang G: Studies on implementation of the Katsevich algorithm for spiral cone-beam CT. Journal of X-ray Sci. and Tech. 12:97-116, 2004).

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| *(a) (b)* |
| *Implementation of the Katsevich algorithm. (a) An illustration of PI Segment, and (b) Local coordinate system for cone-beam projection measurement on a planar detector (Yu HY, Wang G: Studies on implementation of the Katsevich algorithm for spiral cone-beam CT. Journal of X-ray Sci. and Tech. 12:97-116, 2004).* |

**Algorithm 2006 –** The third is the 3D weighting spiral cone-beam/multi-slice algorithm, which was obtained by modifying the first spiral cone-beam algorithm, well-tested and **clinically used on 16- and 64-slice CT scanners** as described in Tang XY, Hsieh J, Nilsen RA, Dutta S, Samsonov D, Hagiwara A: A three-dimensional-weighted cone beam filtered backprojection (CB-FBP) algorithm for image reconstruction in volumetric CT—helical scanning. Med. Phys. 51:855-874, 2006.

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| *(a)  (b)* |
| *Schematic diagrams showing the geometries in which the 3D-weighted helical CB-FBP reconstruction algorithm is derived. (a) The native CB geometry, and (b) the cone-parallel geometry (Tang XY, Hsieh J, Nilsen RA, Dutta S, Samsonov D, Hagiwara A: A three-dimensional-weighted cone beam filtered backprojection (CB-FBP) algorithm for image reconstruction in volumetric CT—helical scanning. Med. Phys. 51:855-874, 2006).* |

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| *Simulated body phantom with 64 9x0.625 mm detector configuration and 63/64 helical pitch. (a) The reconstruction using the 3D weighting algorithm with tangential filtering and 3D weighting, and (b) the counterpart using the Katsevich algorithm (Hsieh J, Nett B, Yu Z, Sauer K, Thibault JB, Bouman CA: Recent advances in CT image reconstruction. Curr. Radiol. Rep. DOI 10.1007/s40134-012-0003-7, 2013 (in Advances in CT Imaging (NJ Pelc, Section Editor, Springer Science+Business Media New York 2013).* |

Although the Katsevich algorithm is theoretically exact by performing the projection filtration along tilted paths tangent to the scanning helix, the same paths are incorporated into the 3D weighting reconstruction to improve image quality in the above figure, which shows a numerical phantom with the 3D weighting algorithm and the Katsevich algorithm respectively to produce comparable image quality.

**Comments –** Several general comments on the above three algorithms are in order.

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| ***Algorithm*** | ***Pro*** | ***Con*** |
| ***1991*** | *Most computationally efficient, with several desirable exact reconstruction properties, and applicable to irregular scanning trajectories as well* | *Artifacts associated with a large cone angle* |
| ***2004*** | *Theoretically exact yet in the filtered backprojection format* | *Noise distribution is not optimal* |
| ***2006*** | *Good balance between cone-beam artifacts and image noise distribution* | *Slightly compromised in-plane resolution due to cone-parallel rebining* |

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