Toward Model-Based Reconstruction in Scanned Baggage Security Applications

Pengchong Jin*, Eri Haneda*, Charles. A. Bouman*, and Ken D. Sauer**
*** Electrical and Computer Engineering, Purdue University, West Lafayette, IN USA 47906**
**** Department of Electrical Engineering, University of Notre Dame, Notre Dame, Indiana 46556**

Abstract

Our research objective is a general implementation of model-based reconstruction for multi-slice helical scan CT geometry with application to transportation security screening.

Model-based reconstruction has several potential advantages compared to traditional filtered backprojection (FBP) reconstruction including:

- Reduced artifacts such as metal streaks
- Reduced noise
- Improved Image resolution

Multi-slice helical CT

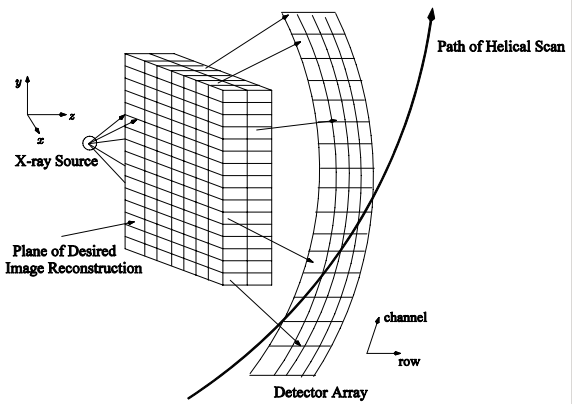


Fig 1. Multi-slice helical CT geometry

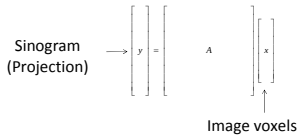
- Multi-slice helical CT has a cone-beam structure
- Gantry (X-ray source, detector array) rotates around an object in a helical scan path.
- Detector array consists of hundreds of channels and several rows.

- In our projection model, each voxel was flattened along the dimensions parallel to detector face.

Model-based reconstruction

Forward projection

Multi-slice helical CT scanner forward projection can be modeled by a linear matrix operation:



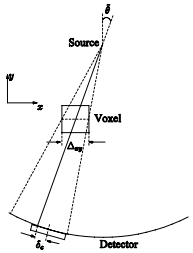
- The forward matrix A is defined by CT geometry and image representation
- The *j*-th column of A corresponds to projection of voxel *j*.
- Each column entry is calculated as a product of XY-plane projection $B_{i,j}$, and Z-direction adjustment factor $C_{i,j}$ for *i*-th detector element.

$$A_{i,j} = B_{i,j} \times C_{i,j}$$

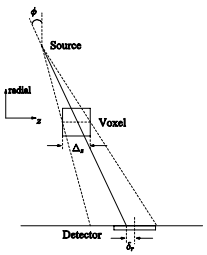
$$B_{i,j} = \frac{\Delta_{xy}}{\cos\theta} V_c(\delta_c) * S_c(\delta_c)$$

$$C_{i,j} = \frac{1}{\cos\phi} V_r(\delta_r) * S_r(\delta_r)$$

Δxy : Voxel size
θ, ϕ : Ray angle in xy-plane and z-direction
δc, δr : Offset from detector element center
V : voxel window function
S : Detector sensitivity function



XY-plane



Z-direction

MAP estimation

$$\hat{x} = \arg\min_{x} \left\{ \frac{1}{2}(y - Ax)^T D(y - Ax) + U(x) \right\}$$

x : Reconstructed image values
y : Measured CT projection (sinogram)

- Log-likelihood term for x-ray transmission is based on a second-order Taylor series expansion.
- *D* is a diagonal matrix where we assume an identity matrix.
- Log-prior *U(x)* is a regulation term for smoothness

Log-prior term

We used a quadratic GMRF prior with p=2 for *U(x)*

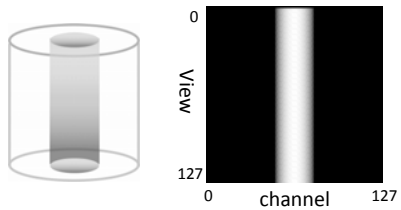
$$U(x) = \frac{1}{p\sigma^p} \sum_{\{i,j\} \in C} g_{i,j} \left| x_i - x_j \right|^P$$

Optimization

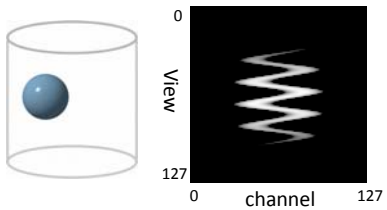
Iterative Coordinate Descent (ICD) method was used
ICD was performed with 30 iterations

Preliminary low resolution test results

Forward projection

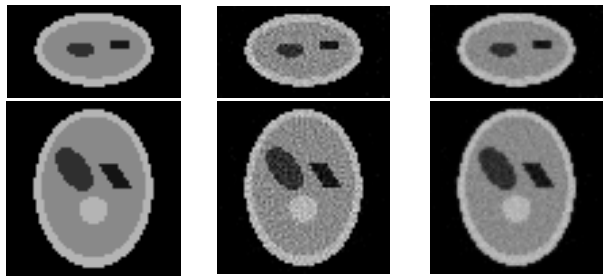


(a) Cylinder object



(b) Off-centered sphere

Model-based reconstruction (white noise was added to the simulated sinogram)



Accomplishments

- Designed and implemented distance-driven based forward projection for multi-slice helical CT scanner
- Implemented model-based reconstruction with a quadratic prior and ICD optimization
- Simulated reconstruction using phantom data

Future work

- Implement non-quadratic prior model
- Optimize and parallelize code
- Apply model-based reconstruction to real data
- Evaluate model-based reconstruction on a variety of real and simulated data
- Develop a statistical model for more accurate CT baggage reconstruction

References

[1] J.B. Thibault, K. Sauer, C. Bouman, and J. Hsieh, "A three-dimensional statistical approach to improved image quality for multi-slice helical CT," Med. Phys., vol. 34, no. 11, pp. 4526-4544, 2007.
[2] K. Sauer and C. Bouman, " A local update strategy for iterative reconstruction from projections," IEEE Trans. On Signal Processing, vol. 41, no 2, 1993

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the U.S. Department of Homeland Security.