X-ray CT-based EDS Research Problems

Zhengrong Ying

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Conclusion

* Next generations X-ray CT-based EDS
  * Improved throughputs
  * Expanded detection regions
  * Reduced FA rates
  * Lower costs
* Areas for improvements
  * System Geometries
  * Object-based Image Reconstruction
  * Computer Assisted Training
  * Multi-energy Decomposition

System Geometries

* Existing CT-based EDS
  * Rotating CT (RCT)
    * Single-helix scanning
    * Dual-helix scanning (medical)
      * Siemens DSCT
      * Larger scanning pitch
  * Stationary CT (SCT)
    * Mimicking RCT geometry
      * Sources within X-Y plane
      * Single- and multi-helix scanning
* SCT advantages
  * Flexible geometry due to many sources (RCT: views)
    * Arbitrary source positions (RCT: X-Y rotating plane)
    * Arbitrary source firing sequences (RCT: sequentially only)

System Geometries (cont.)

* SCT Example 1
  * Given a belt speed, arrange the sources along the Z axis and firing sequence along the scanning helix direction, resulting in a 2D acquisition mode;
    * No sampling between slices;
    * Data is complete within each slice (2D problem);
    * Still an issue for cone-beam data
* SCT Example 2
  * Source positioning
    * helix + saddle curve [Pack 2004]
  * Data completeness for 3D cone-beam

System Geometries (cont.)

* Most theoretical analysis in CT is in continuous domain
  * Data completeness condition [Tuy 1983]
  * Single Helix [Katsevich 2002] (small pitch)
  * Saddle curve [Pack 2004]
* Implementation is in discrete domain
  * # of sources (views)
    * Data completeness in discrete domain?
    * Relation to spatial resolution?
  * Difficulties
    * 3D volume sampling
    * Sampling in polar coordinates (line integral)
    * Image in Cartesian grids
    * Finite sizes of sources and detectors

Object-based Image Reconstruction

* Existing EDS
  * Single reconstruction
  * Multi-detection paths
    * Thin-object
    * Bulk-object
    * …
* Next-Gen EDS
  * Multi-reconstruction paths
    * Thin-object
    * Bulk-object
    * Metal
  * Multi-detection paths

Object-based Image Reconstruction (cont.)

* Existing image reconstructions
  * Voxel/pixel based
  * Regularization with smoothness priors
    * Maybe good enough for bulk-object reconstruction
  * Regularization with edge-preserving priors
    * Not enough for thin-object recon
      * Thin object may only have one voxel thick
      * Continuation property of a thin object is not imposed
      * Continuation of smooth surfaces of a thin object is not captured
* How to perform reconstruction targeted for thin-objects?
  * The most difficult problem for detection and FA rates
  * Many configurations of thin-objects

Computer Assisted Training

* Most training methods in the literature
  * One training stage, then it's done
    * Not an iterative training process
  * No feedback into the re-training
  * Treat all the training samples equally
  * No easy interface for humans to understand/interact
* Two CAT problems
  * Feature dependence discovery
  * Iterative training process

Computer Assisted Training (cont.)

* Feature dependence discovery
  * Examples:
    * Average densities of thin-objects are location/orientation dependent
    * Average density of objects depend on the nearby objects along the same beam paths
  * How to identify such correlations in a large feature set?
    * Help obtain physical explanations of such correlations
    * Use the features appropriately to yield the best generalization for discrimination

Computer Assisted Training (cont.)

- Iterative training process
  - Step 1: based on first training data sets, obtain an optimal discrimination algorithm
    - SVM, linear, nonlinear, …
    - Start with a low Pfa
  - Step 2: based on feedback from testing, obtain targeted samples of misses, re-train the discrimination algorithm with the following constraints
    - The detection region monotonically increases
      - Detection region in Step 1 is a subset of the updated detection region
    - Some samples of misses must be detected
    - Some samples of misses can be missed
    - FA rate increase is minimized
    - Same global criterion as Step 1 for optimization
  - Continue till pass the cert

Multi-energy Decomposition

* Dual energy decomposition [Alvarez 1976]
  * Two terms modeling
    * Compton + Photoelectric
  * Two measurements
* Multi-energy decomposition
  * K-edge effect?
    * Many metals in the baggage scanning
  * Do more than two measurements help improve SNR?
    * How much? Any theoretical analysis?
    * How to deal with data inconsistence in the measurements?
  * What X-ray spectra give an optimal SNR for baggage screening?

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