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Image Reconstruction from Sparse-view Data Acquired with Portable X-ray Devices

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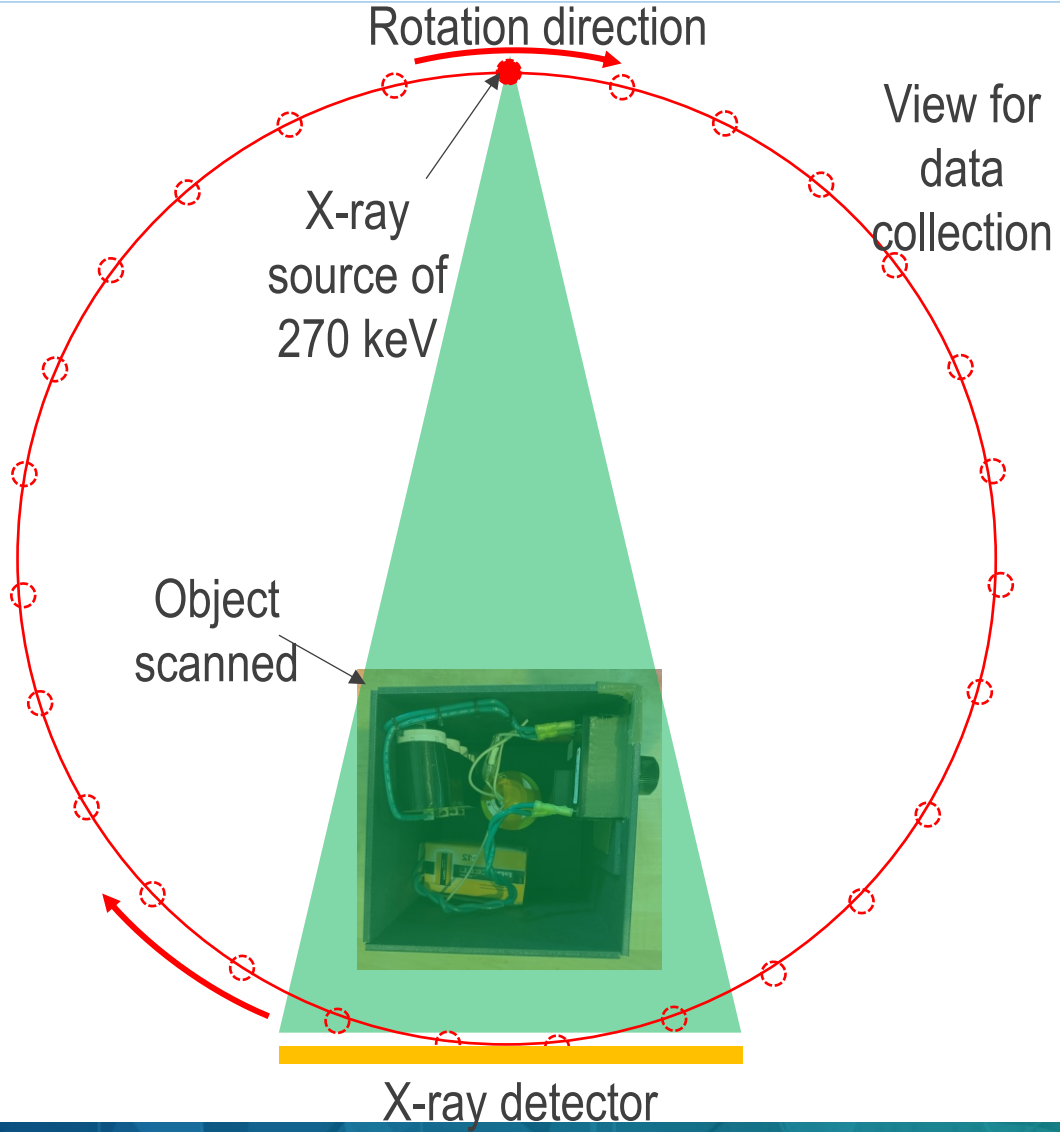
BSRA Battelle Savannah River Alliance, LLC

Introduction

- Portable X-ray systems enable on-site 3D imaging for non-invasive inspection of suspicious packages and explosives.
- Existing reconstruction algorithms (e.g., FDK or Feldkamp, Davis and Kress) require hundreds of projections over 360 degrees.
- Sparse-view scan reduces scanning time and setup effort, making it ideal for field use in time-critical scenarios.
- Existing reconstruction algorithms introduce severe artifacts when applied to sparse-view data.
- We developed a total variation (TV)-based optimization algorithm for yielding 3D images from sparse-view data collected with our portable X-ray imaging system.

Cone-beam-CT Sparse-view Scan



- Angular ranges of 360°
- Sparse-view scans: 45 and 12 views
- Non-uniformly distributed views
- Non-circular trajectories
- Cone-beam illumination at each view

Image Model and Reconstruction

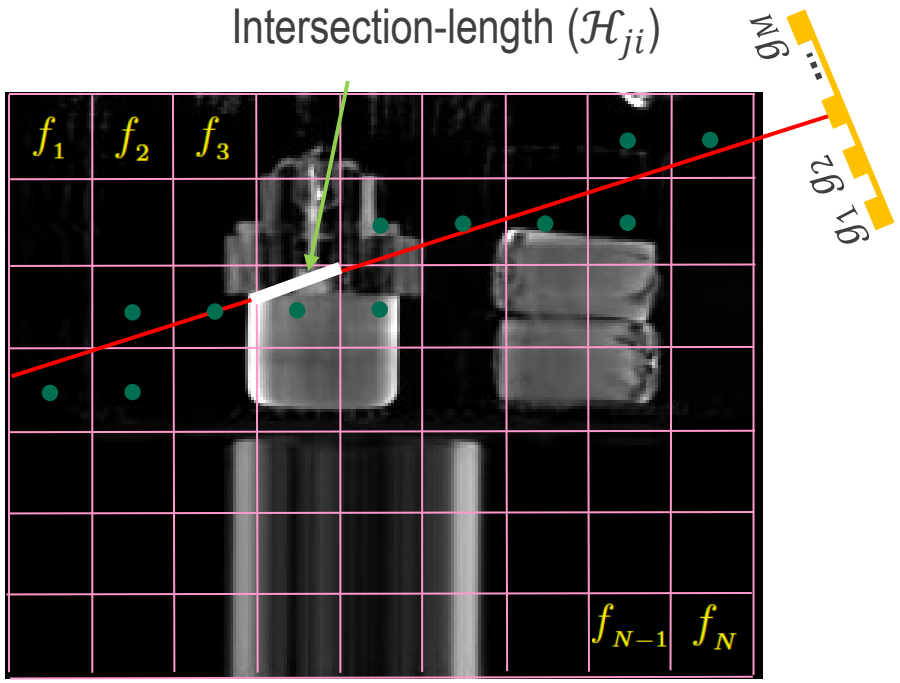


Image model – discrete X-ray transform

$$g = \mathcal{H}f$$

g: discrete model data
f: discrete image
$\mathcal{H}$: system matrix, each element $\mathcal{H}_{ji}$ denotes the intersection-length of ray *j* and voxel i

Observation: Image reconstruction is equivalent to inverting the linear equation set.

Matrix $\mathcal{H}$ encodes the system geometry and can accommodate arbitrary angular sampling schemes, including full 4π and partial 4π configurations, with either uniform or non-uniform angular distributions.

Optimization-based TV Reconstruction

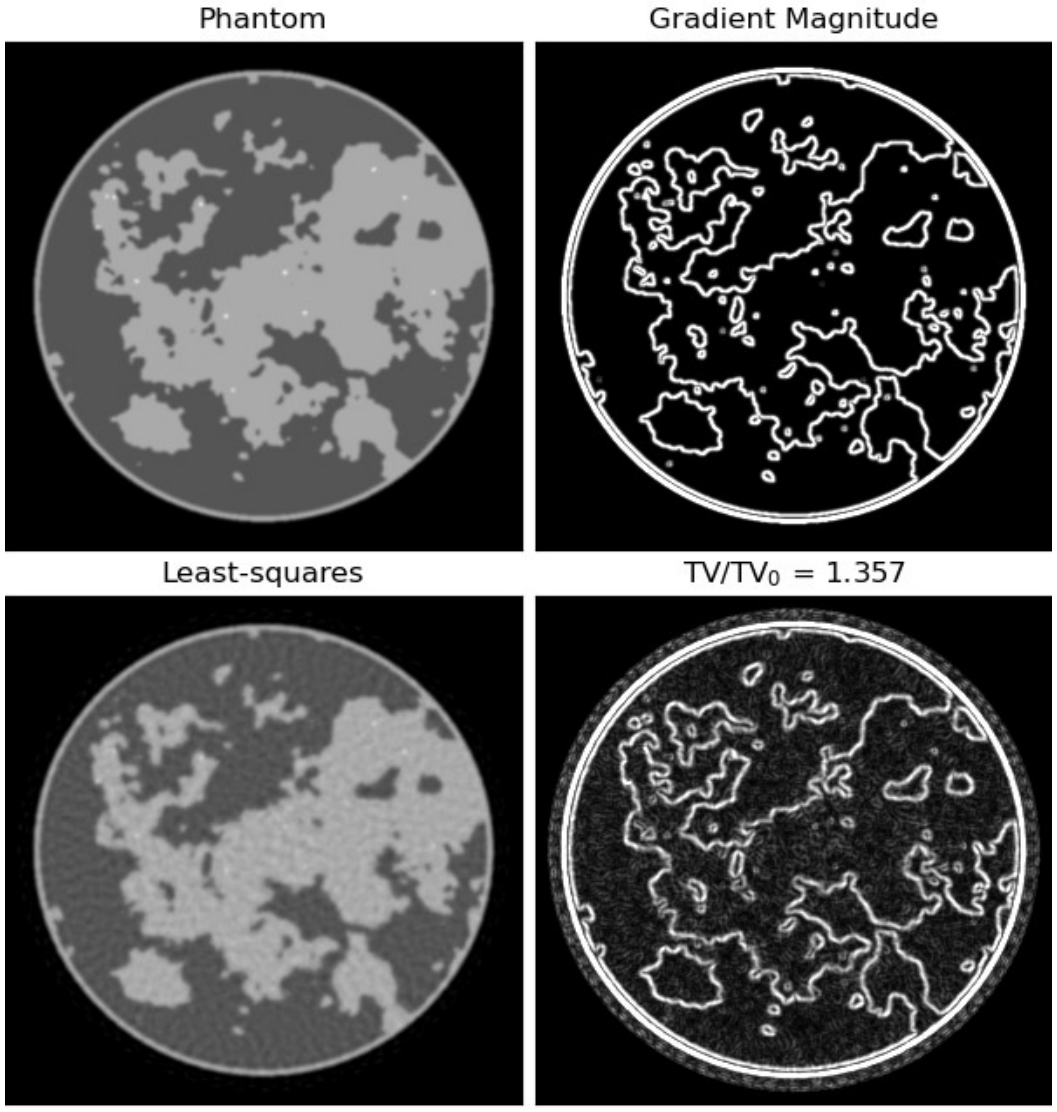
Image reconstruction is formulated as a constrained optimization program:

$$\mathrm{f}^* = \underset{\mathrm{f}}{\operatorname{argmin}}\left\{ \|\nabla \mathrm{f}\|_1 \right\},$$

$$s.t. \quad \left\|(\mathcal{H}\mathrm{f} - \mathrm{g}^{[\mathcal{M}]})\right\|_2 \leq \varepsilon, \text{ and } \mathrm{f}_i \geq 0$$

- Objective function
  - convex total-variation fidelity, in which $\|\nabla \mathrm{f}\|_1$ denotes ℓ_1-norm of the gradient magnitude image.
- Constraints:
  - data-ℓ_2 constraint, and non-negative parameter, ε, is used to control the inconsistency between measured data (i.e., $\mathrm{g}^{[\mathcal{M}]}$) and modeled data (i.e., $\mathcal{H}\mathrm{f}$).
  - non-negativity constraint is on image

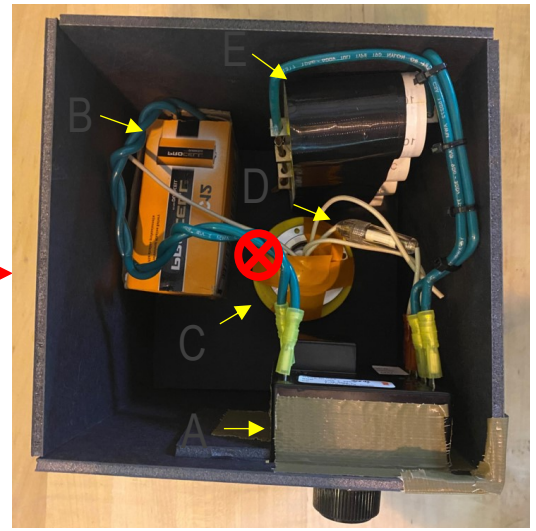
Rationale for TV Minimization



- Sparse view configuration leads to underdetermined imaging model.
- Both phantom and least-squares (LSQ) image solve $g = \mathcal{H}f$ exactly.
- Phantom is sparse in the gradient magnitude image (GMI), while LSQ image is not sparse in the GMI.
- Total variation (TV) measure is the sum of GMI pixel values.
- TV of LSQ image is greater than TV of phantom.
- Minimization of the TV rules out the LSQ image (and hopefully all other images that solve $g = \mathcal{H}f$).

Scanned Object and Scanning Configurations

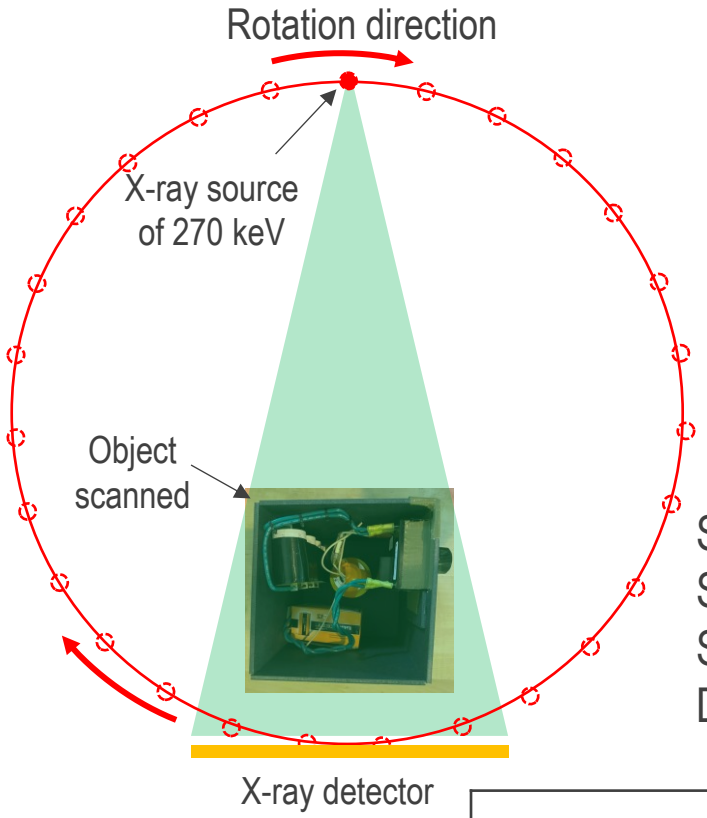
Photo of scanned object



Side view

Front view

A: Timer
B: Battery pack
C: D_2 lamp in Ta cup
D: Inline fuse
E: Capacitor bank

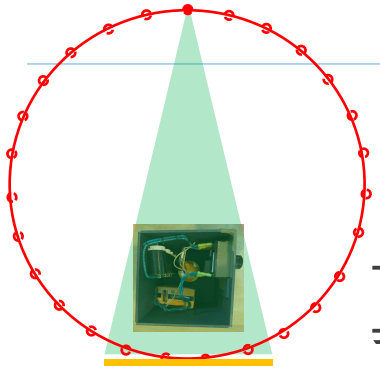


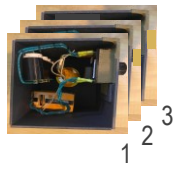
Scanning configuration:
Source-to-rotation-axis distance: 130 cm
Source-to-detector distance: 152.5 cm
Detector size: 1152×1600 bins of size 0.254 mm

	Full data set	Data set 1	Data set2
Number of views	90	45	12
Angular coverage	360°	360°	360°
Angular interval	4°	8°	30°

Transverse Slices and Maximum Intensity Projection (MIP) Images

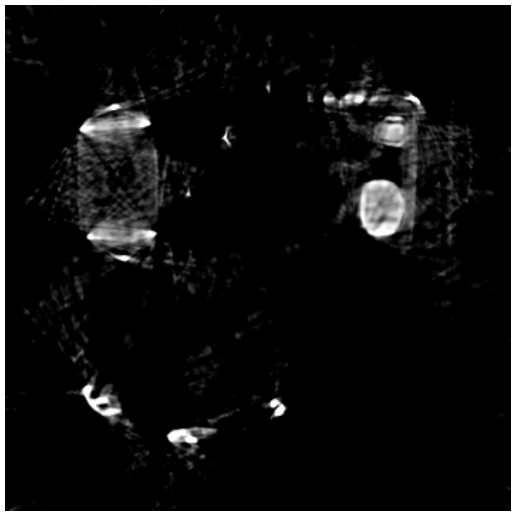
(45 views over 360° with an angular interval of 8°)

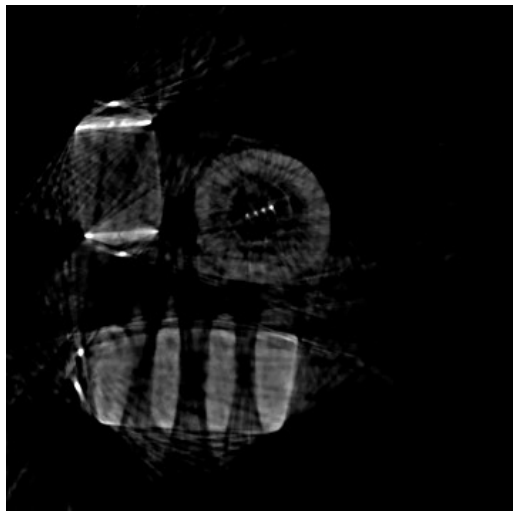


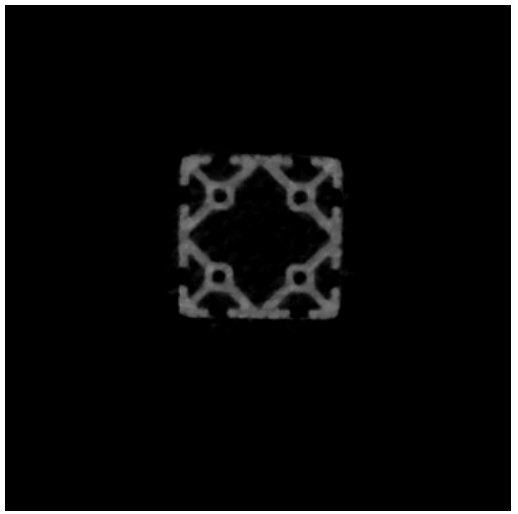


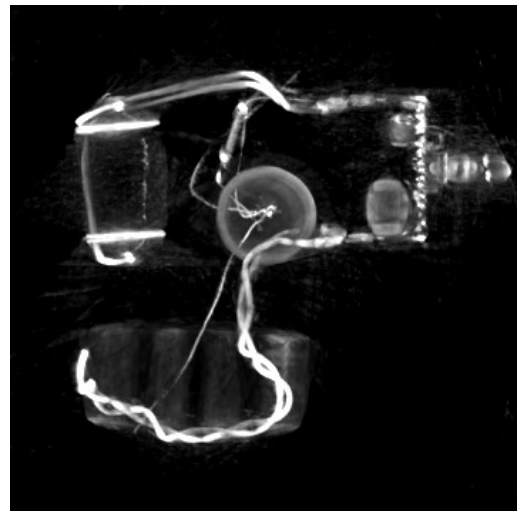
TV method

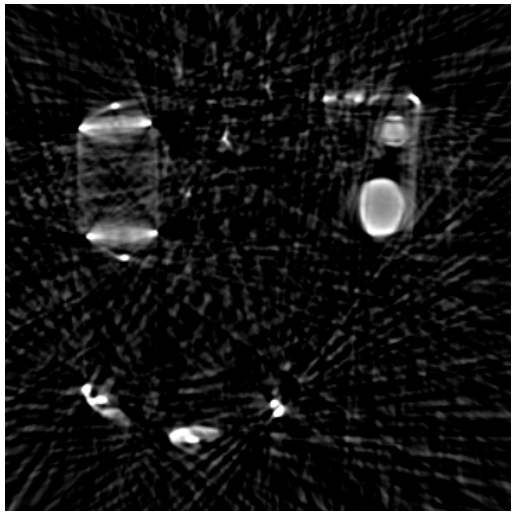
Existing FDK method

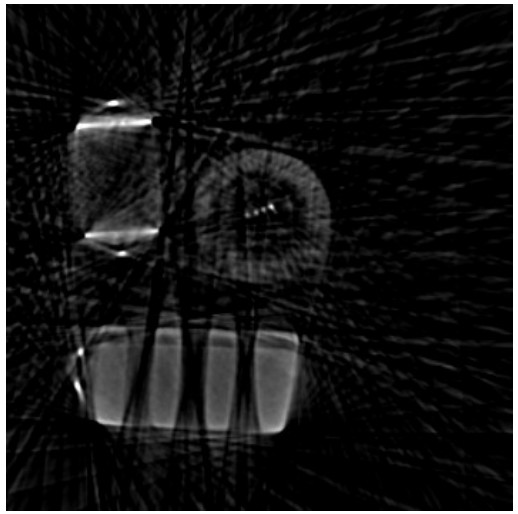


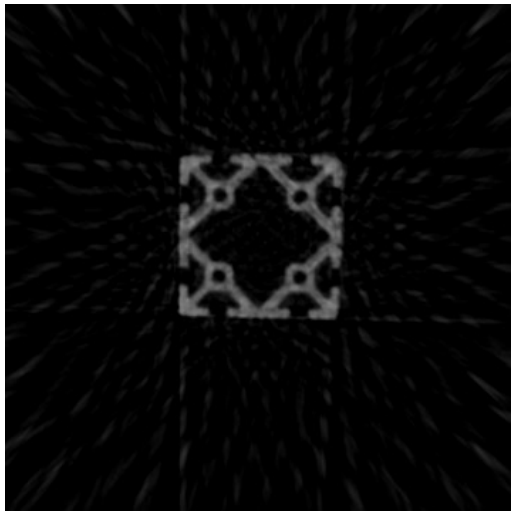


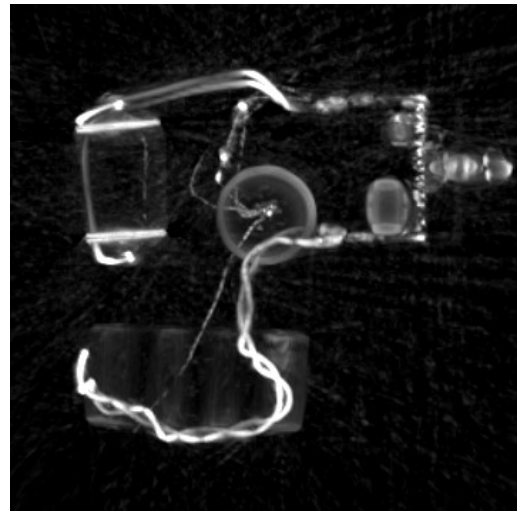








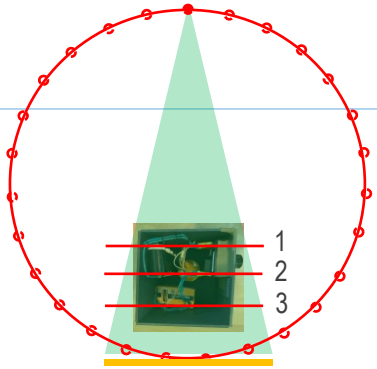


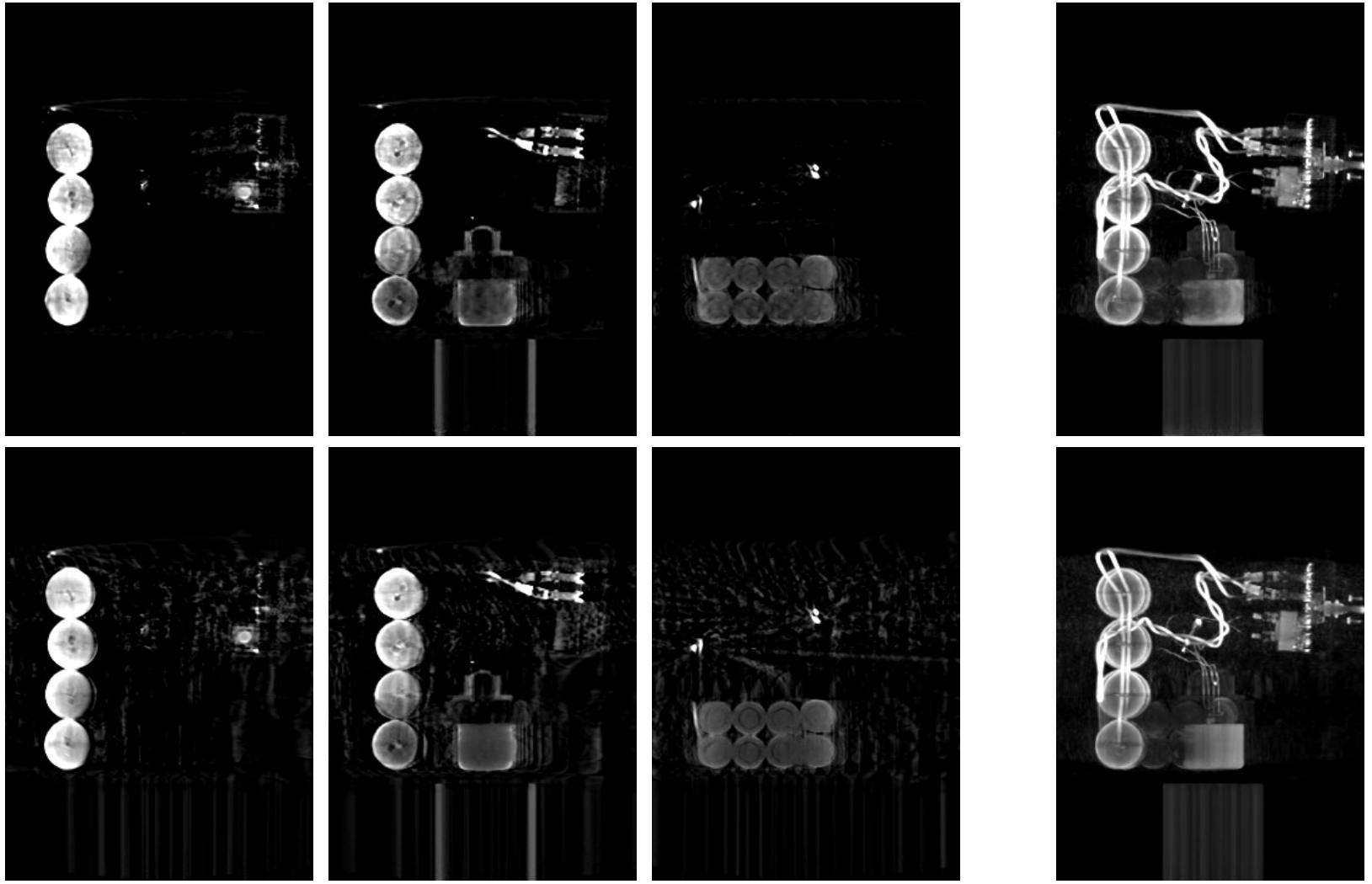


Slice 1 | Slice 2 | Slice 3 | MIP

Coronal Slices and MIP Images

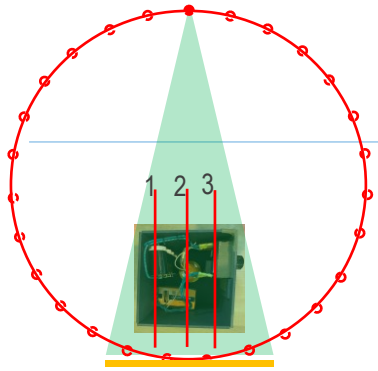
(45 views over 360° with an angular interval of 8°)





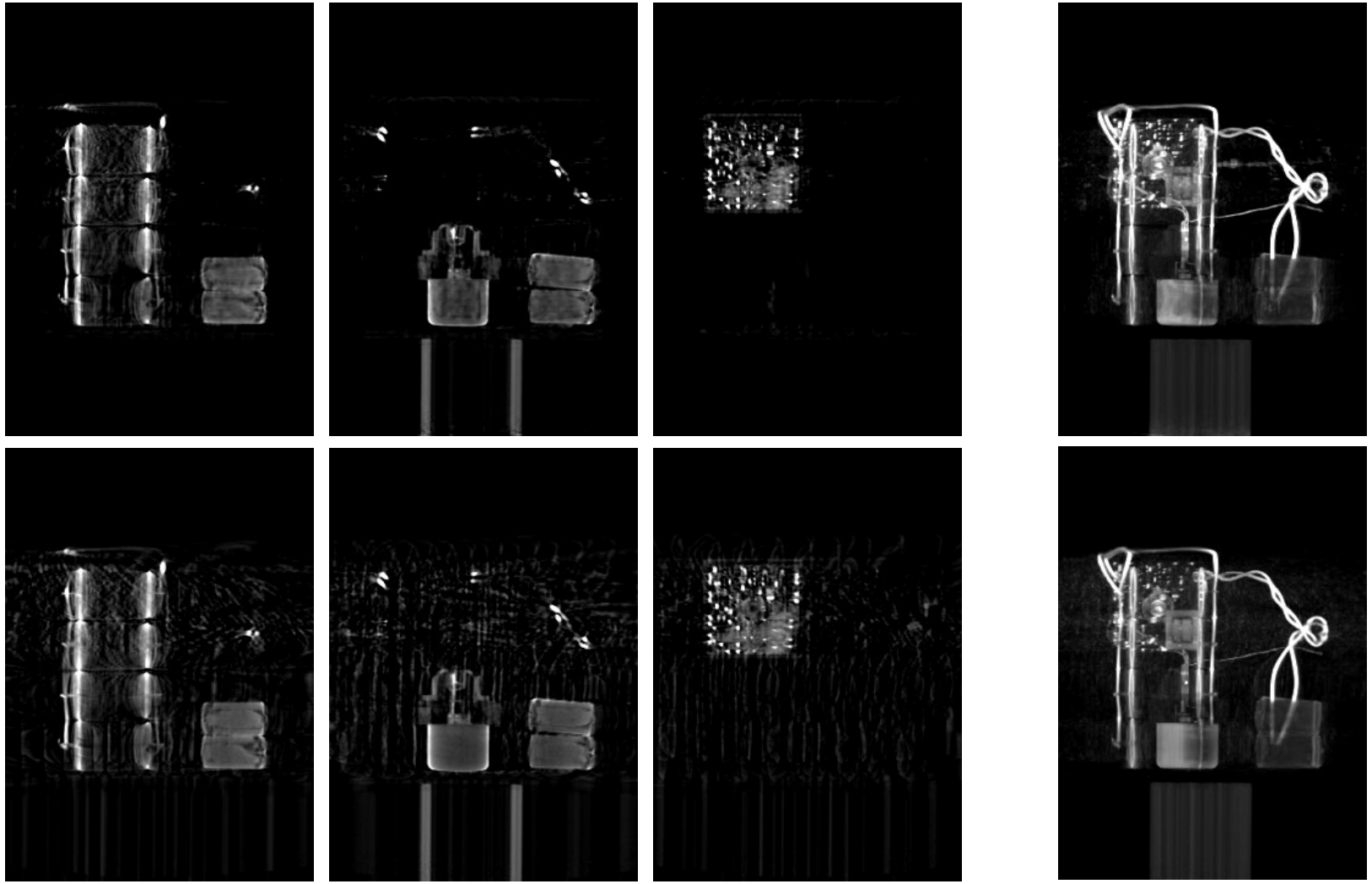
Sagittal Slices and MIP Images

(45 views over 360° with an angular interval of 8°)



TV method

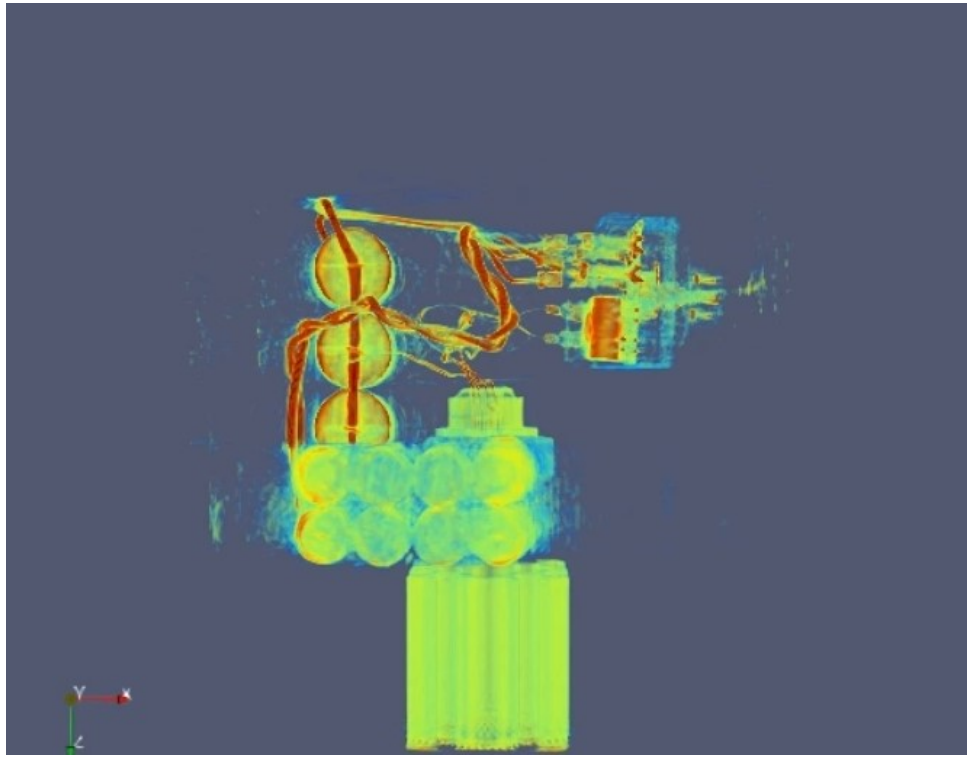
Existing FDK method



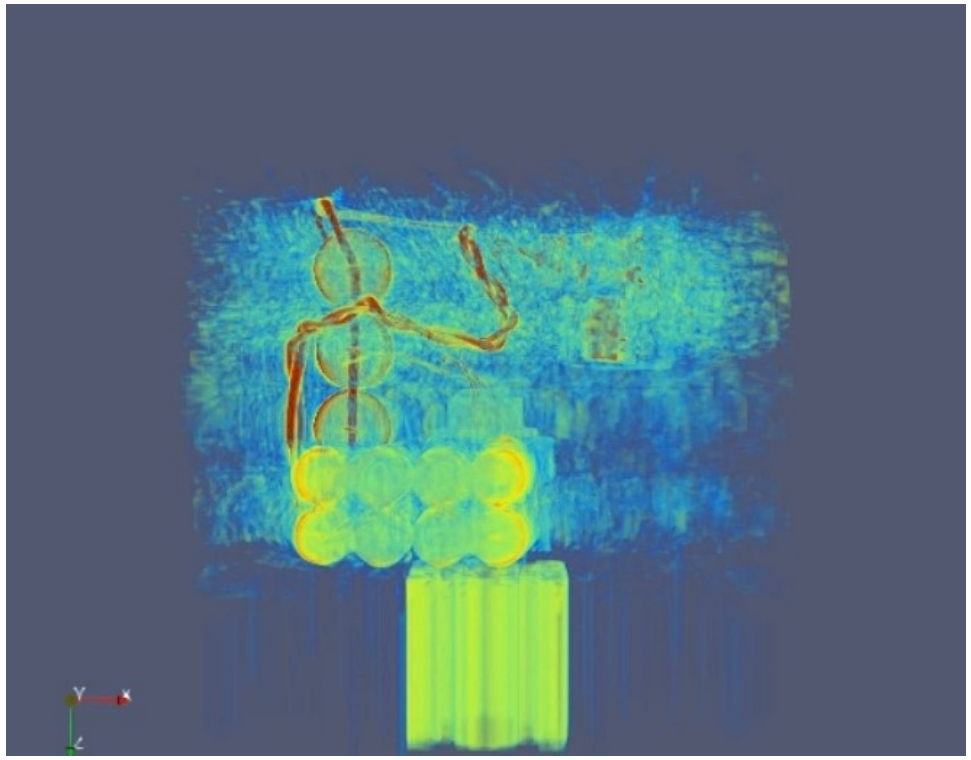
Slice 1 | Slice 2 | Slice 3 | MIP

Rendered CT Images

(45 views over 360^{o} with an angular interval of 8^{o})



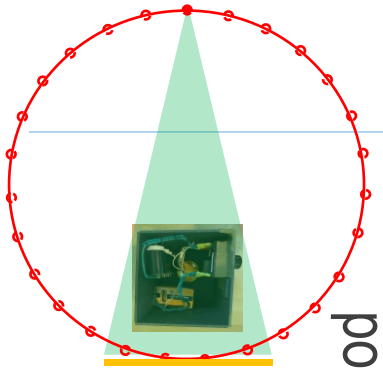
TV method

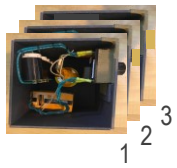


Existing FDK method

Transverse Slices and MIP Images

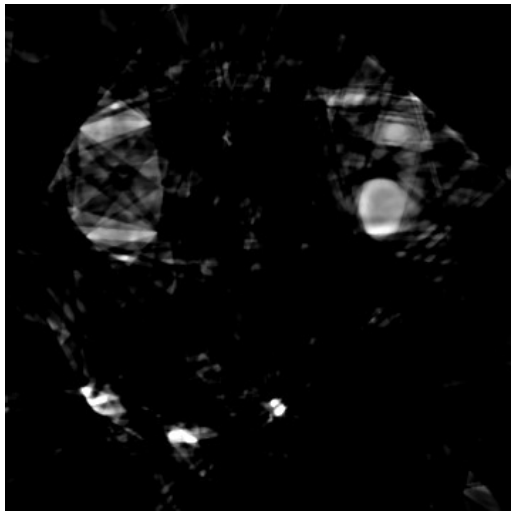
(12 views over 360° with an angular interval of 30°)

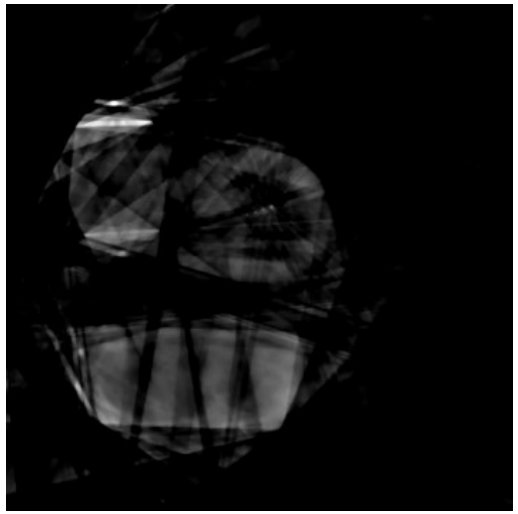


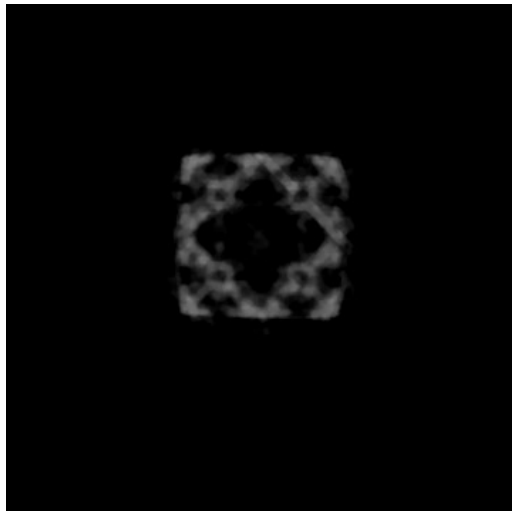


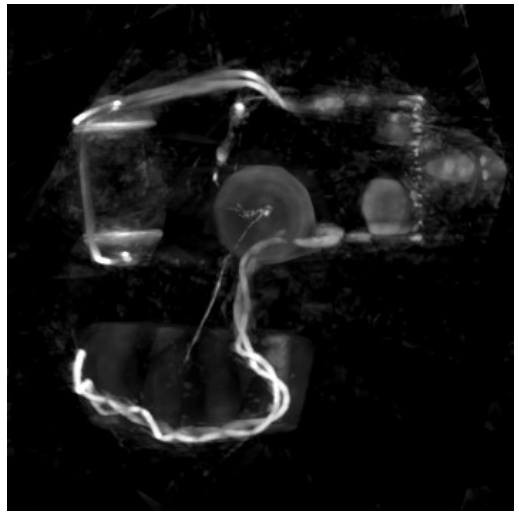
TV method

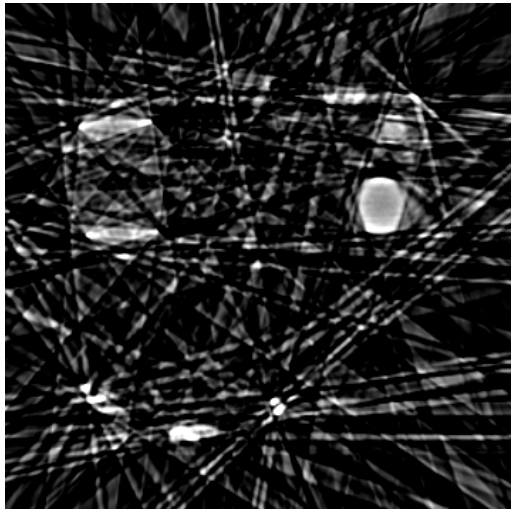
Existing FDK method

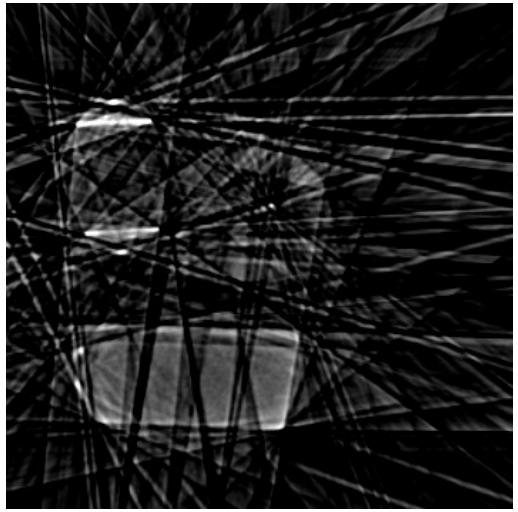


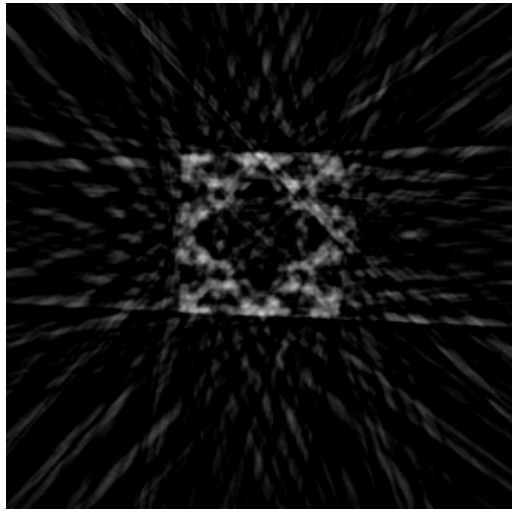


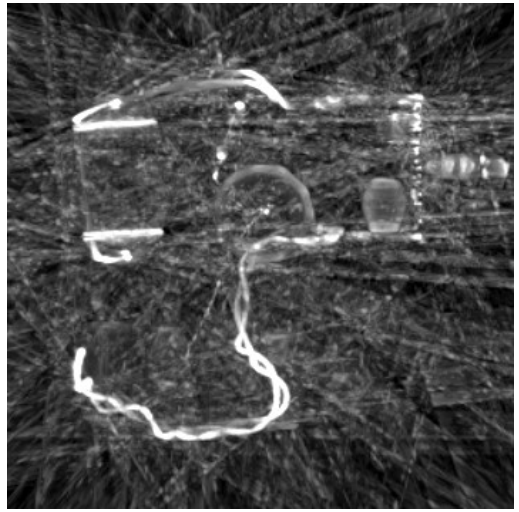








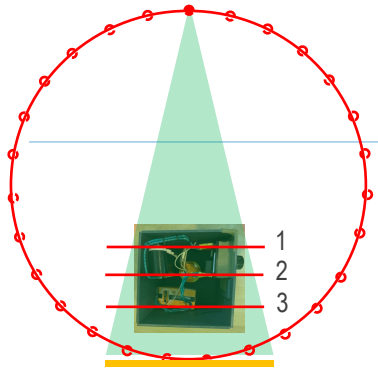




Slice 1 Slice 2 Slice 3 MIP

Coronal Slices and MIP Images

(12 views over 360° with an angular interval of 30°)



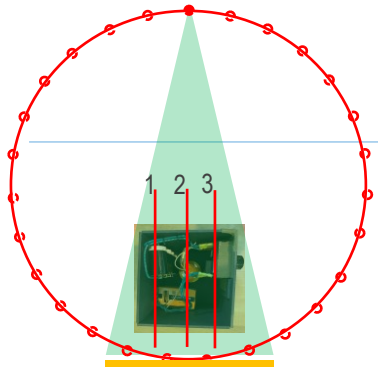
TV method

Existing FDK method

Slice 1 | Slice 2 | Slice 3 | MIP

Sagittal Slices and MIP Images

(12 views over 360° with an angular interval of 30°)



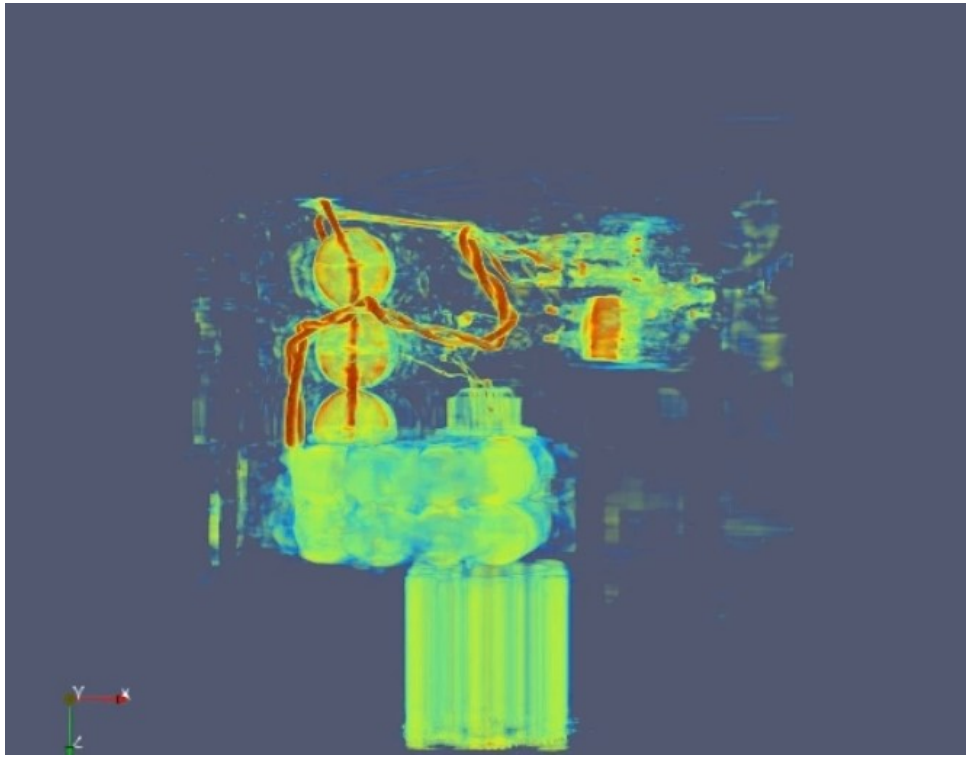
TV method

Existing FDK method

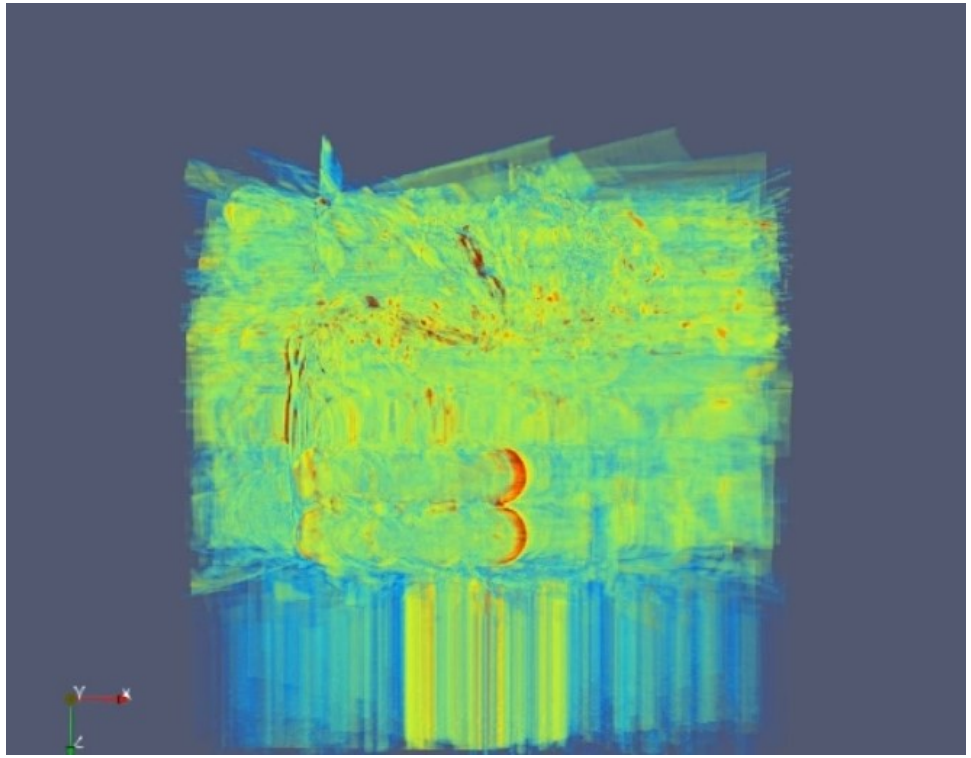
Slice 1 | Slice 2 | Slice 3 | MIP

Rendered CT Images

(12 view over 360^{o} with an angular interval of 30^{o})



TV method



Existing FDK method

Conclusions

- Projection data were collected using a portable X-ray imaging system, with a hand-made phantom of practical relevance
- Developed and tailored a TV algorithm to reconstruct 3D CT images from sparse-view data collected with a portable X-ray imaging system
- Demonstrated that the TV algorithm can yield images with significantly reduced artifacts compared to those obtained with existing algorithms
- Enabled faster data acquisition and supported the use of portable CT imaging in field operations, security screening, law enforcement, and emergency response scenarios

Thank You!

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