Comparison of SART and eTV Reconstruction for increased C-arm CT Volume Coverage by proper Detector Rotation

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Pattern Recognition Lab (CS 5)

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Outline

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- Introduction
- Materials and Methods
  - Scan Modes and Field-of-View Enlargement
  - C-arm CT 3-D Reconstruction
- Results
- Discussion and Outlook

Introduction

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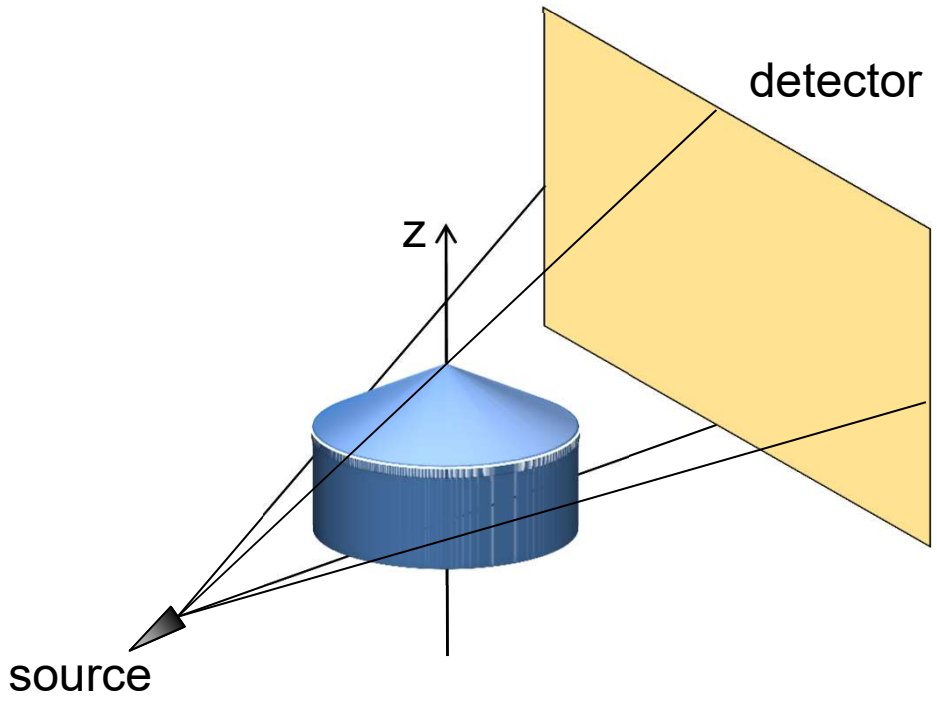
- 3-D imaging uses Short- and Large Volume Scan
- Patient may be still too large to be completely covered

➢ Find method to enlarge the detector‘s field-of-view in *lateral* direction

Materials and Methods

C-arm CT geometry



Cone Beam Geometry

Short Scan

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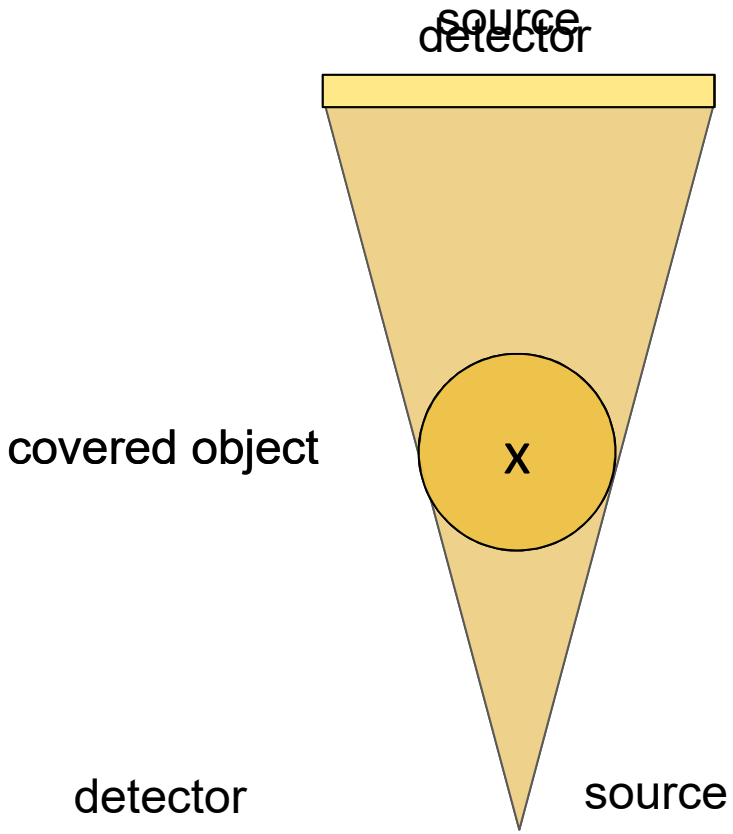
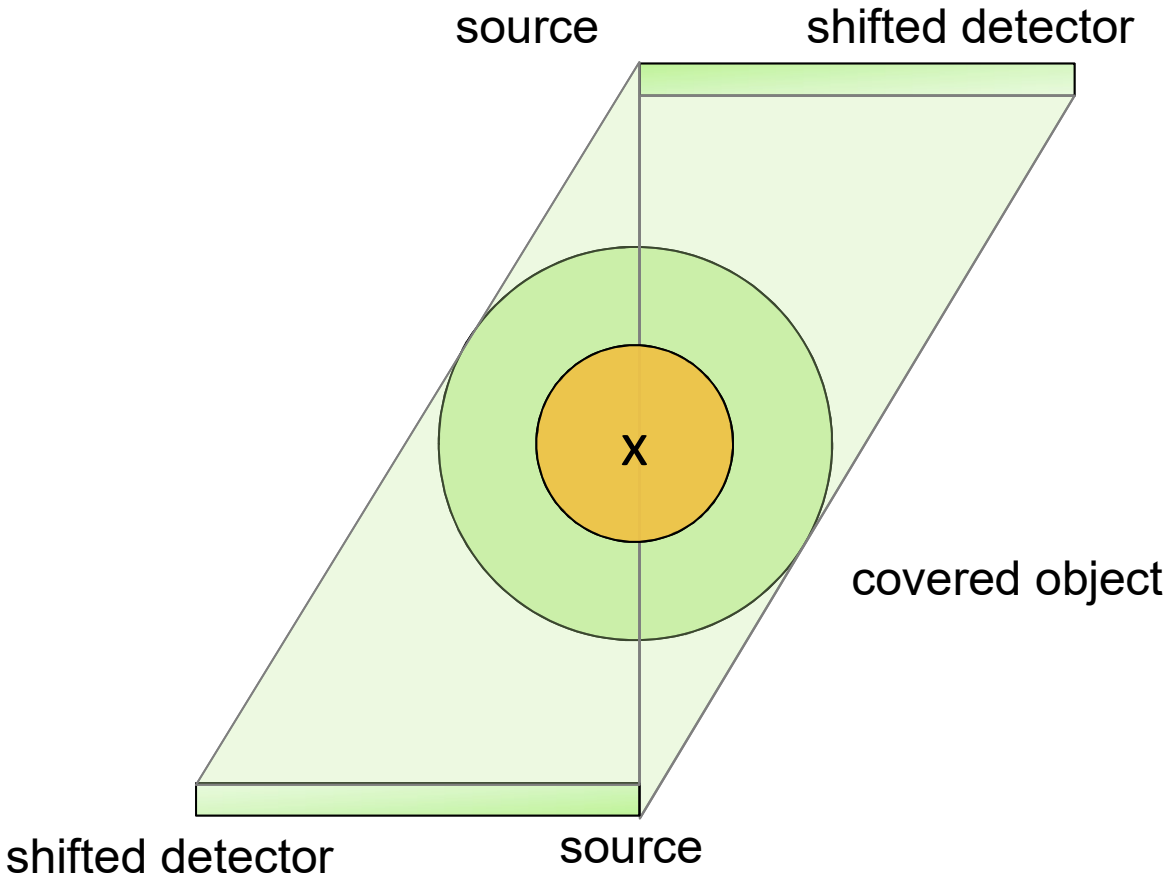
- 200 degree circular scan (180 degrees + fan angle)



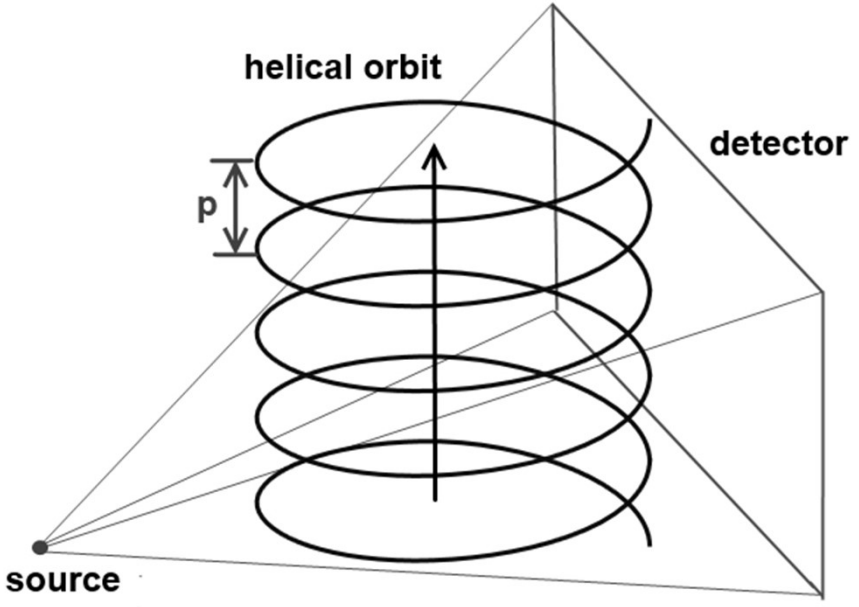
Large Volume Scan

- 360 degree circular scan with shifted detector



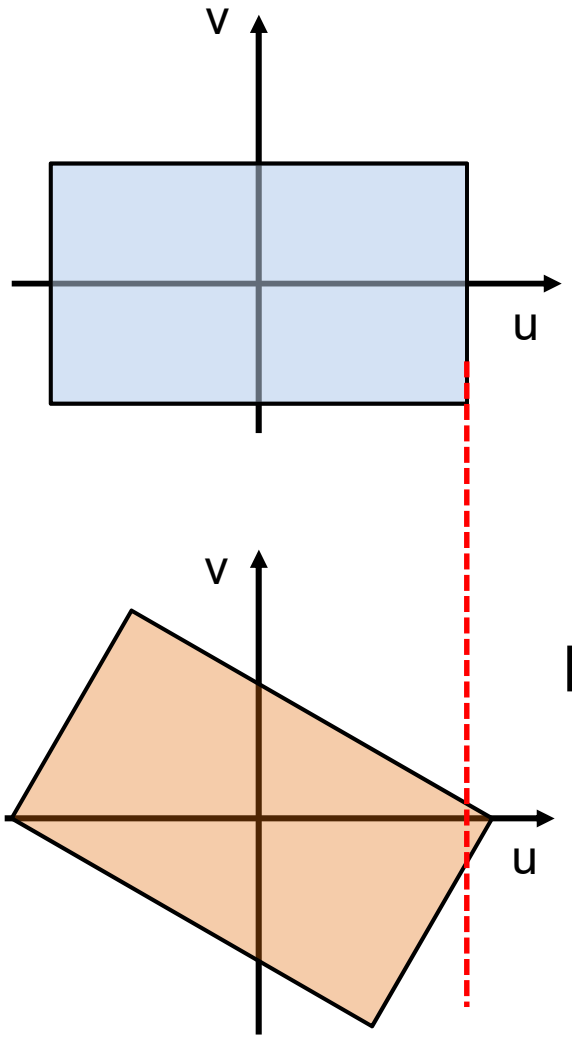
Helical Large Volume Scan

- Similar to Large Volume Scan
- Helical orbit with pitch *p*
- Increased axial coverage

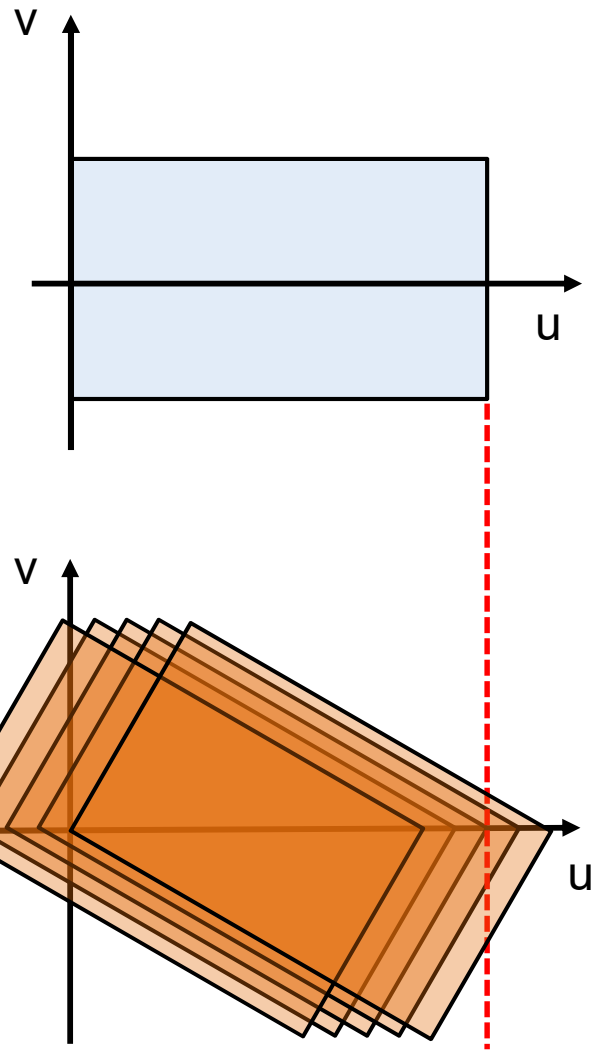


Field-of-View Enlargement

Short Scan



Large Volume Scan



Diamond Scan

Data Completeness Estimation

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- CONRAD Framework used for simulations
  - Detector: 400 mm x 300 mm, SID 1200 mm, SOD 785 mm
- Implemented data completeness estimation
  1. Discrete sampling of the unit sphere in vectors $\boldsymbol{u}$

     #points sampled on the sphere: N_u

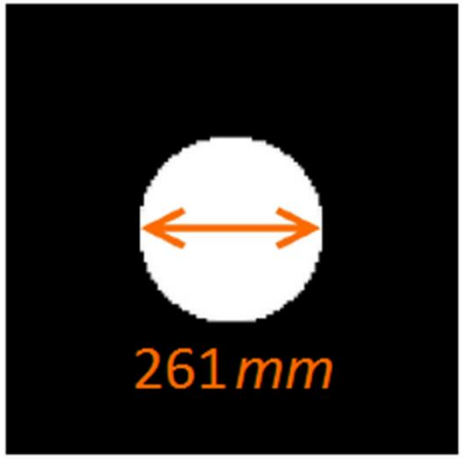
  2. Computation of data completeness in terms of voxel-wise Radon sphere coverage

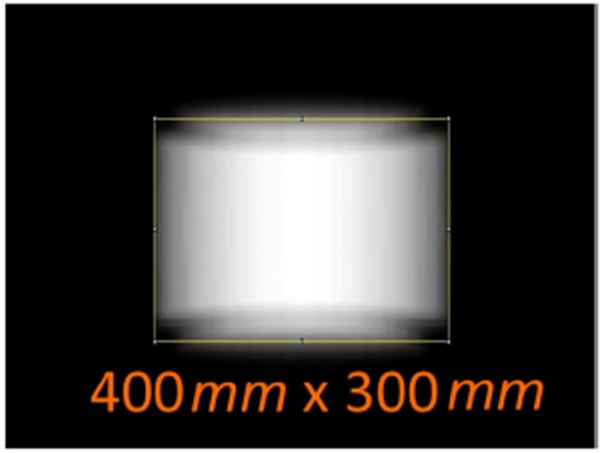
     #unit vectors satisfying the condition: N_c

  3. Resulting Radon sphere coverage

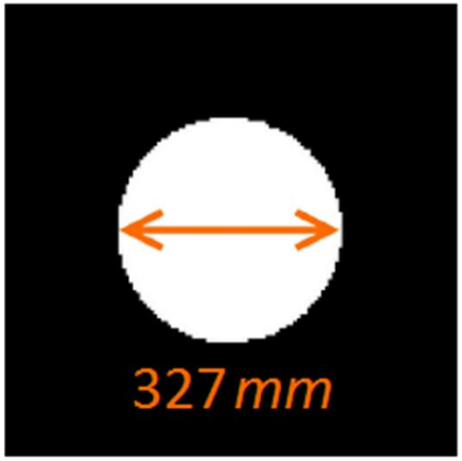
$$c = \frac{N_c}{N_u} \cdot 100\%$$

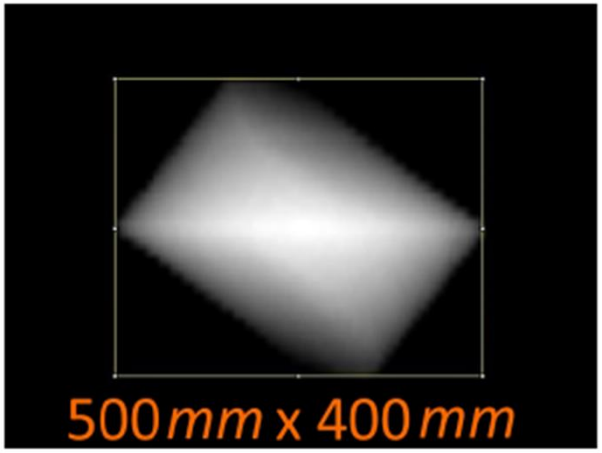
Short Scan coverage





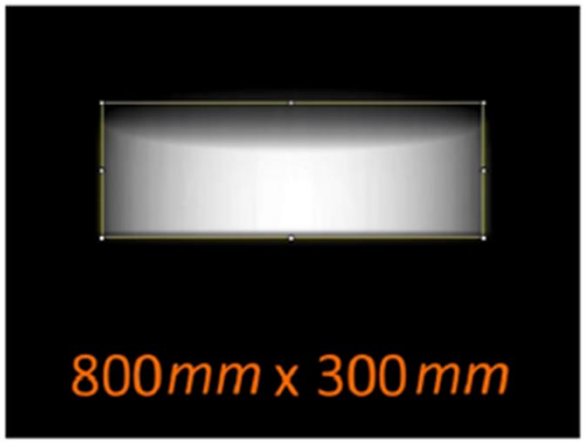
Short Scan Radon sphere coverage and forward projection of the coverage volume



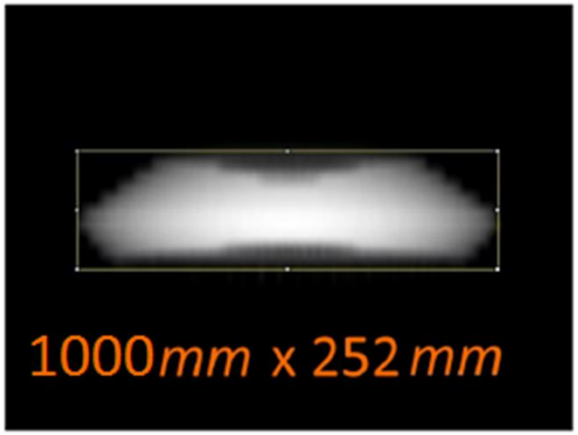


Diamond Short Scan Radon sphere coverage and forward projection of the coverage volume

Large Volume Scan (LVS) coverage

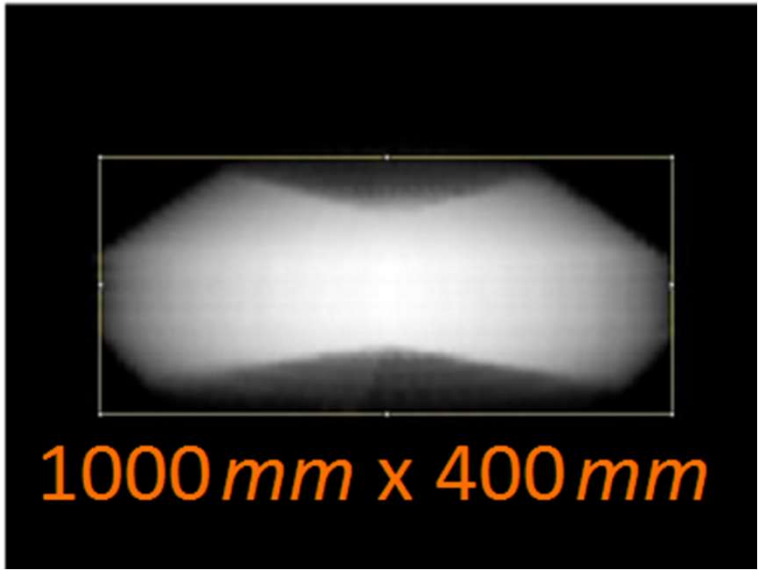


Large Volume Scan
Radon sphere coverage
and forward projection
of the coverage volume



Diamond LVS Scan
Radon sphere coverage
and forward projection
of the coverage volume

Helix coverage



Forward projected volume coverage for Helix Diamond Large Volume Scan

Coverage Results

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Scan Mode	Radon sphere coverage			
	$Standard$ [mm]	$Diamond$ [mm]	$Plus$ [mm]	$Plus$ [%]
Short Scan	261	327	66	25.3
Large Volume Scan	475	605	130	27.3
Helix LVS	475	605	130	27.3

- Coverage increased by 25.3 % for the Short Scan and about 27.3 % for the Large Volume Scans

- Using a helical trajectory compensates the axial loss

C-arm CT 3-D Reconstruction

Basics: Iterative Reconstruction

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- Inverse problem of Radon transform is reformulated as system of equations:

$$p = \boldsymbol{R} \cdot f(\boldsymbol{v})$$

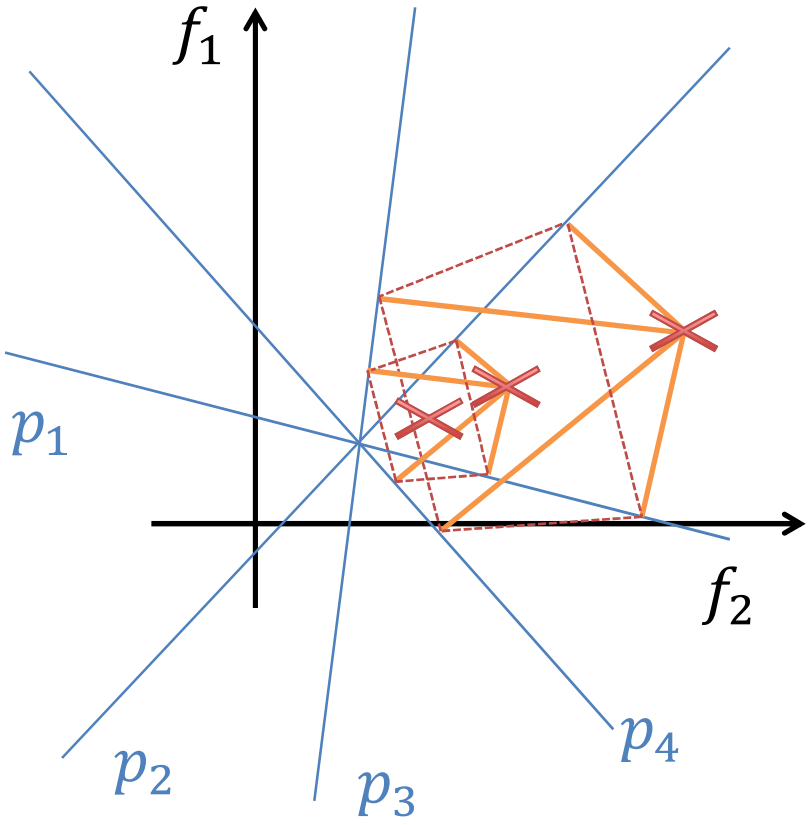
$\boldsymbol{v}$: voxel
p: measured data
$\boldsymbol{R}$: Radon transform

- Minimization of objective function (SSD):

$$\min \left|\left| \boldsymbol{R} \cdot f(\boldsymbol{v}) - p \right|\right|_2^2$$

SART Reconstruction

- Compute orthogonal projections of the current approximation to the hyperplanes
- Compute the centroid and use it for the next iteration



Total Variation Based Reconstruction

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TV-based reconstruction:

- Aim: Raw data fidelity and piecewise constant output
- TV is based on the Compressed Sensing theory

$$\min\left|\left|\psi f(\boldsymbol{v})\right|\right|_1 \text{ subject to } \min\left|\left|\boldsymbol{R}f(\boldsymbol{v}) - p\right|\right|_2^2 < \epsilon$$

  - ψ is a sparsifying transformation of $f(\boldsymbol{v})$
  - ϵ denotes the raw data consistency (similarity measure)

Results

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Configuration

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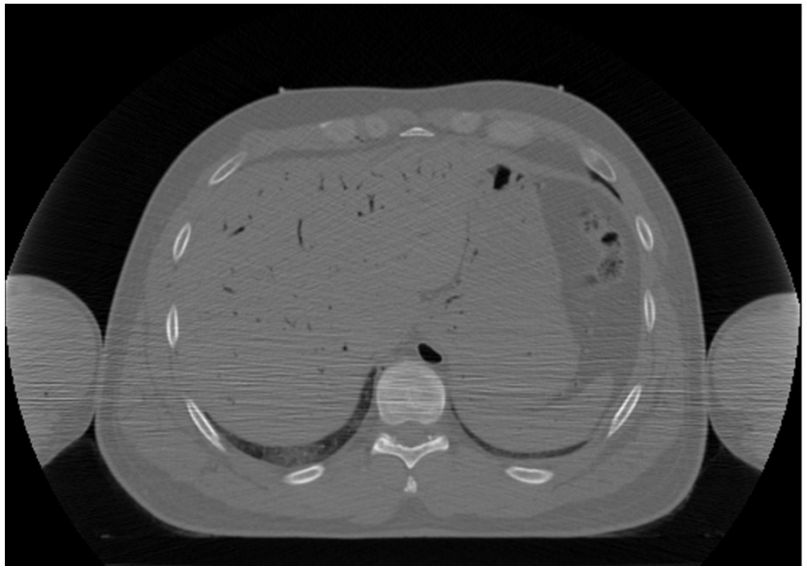
- Visual Human Project data set

Scaling: waist circumference 130 cm (≤ 5% of US American population)
Transversal misalignment of 10% (32mm) was assumed



- Error measurement

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(f_i(v) - \hat{f}_i(v)\right)^2}$$

- Reconstructed with SART and eTV

Reconstruction Results

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Scan Mode	$RMSE_{SART}$	$RMSE_{eTV}$
Short Scan	0.2134	0.1370
Diamond Short Scan	0.2026	0.1242
Standard LVS	0.0608	0.0549
Diamond LVS	0.0322	0.0217
Helical LVS	0.0641	0.0488
Helical Diamond LVS	0.0229	0.0151

- eTV lowers the RMSE compared to SART by 29.1 %

VHP eTV Reconstructions

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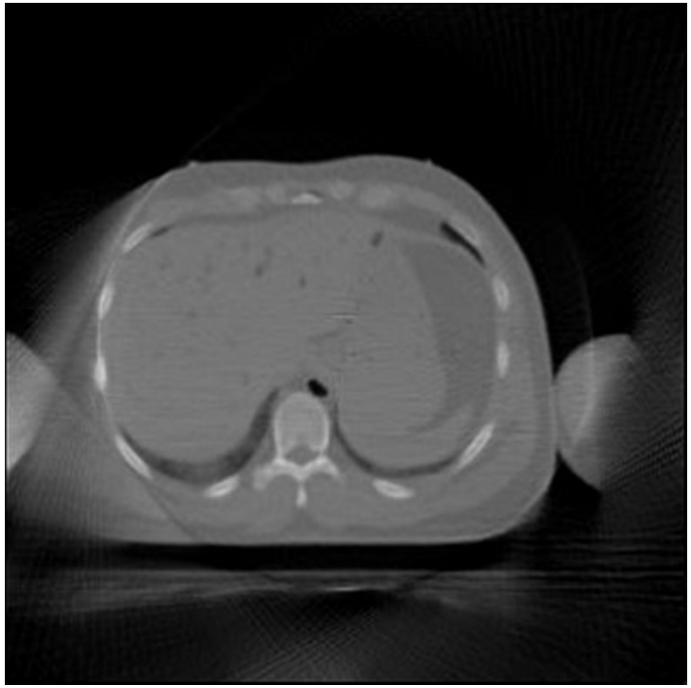
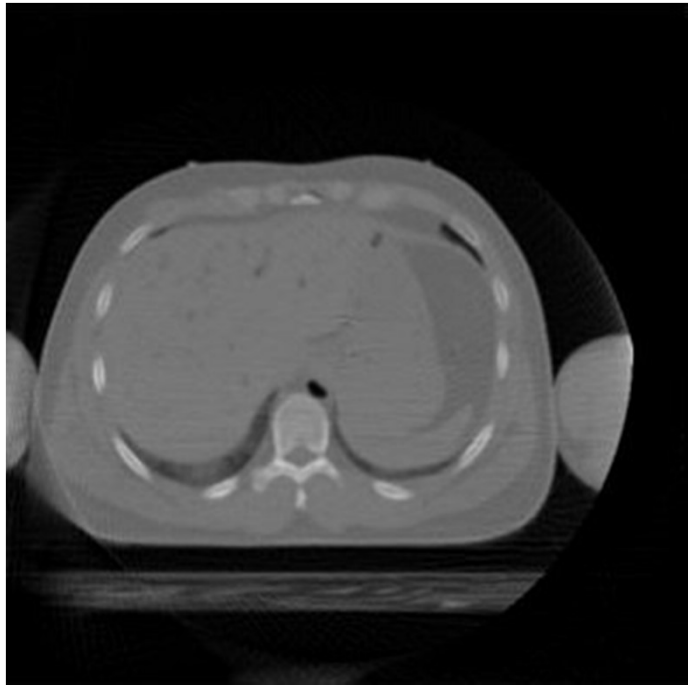
Central Slices (z=15 of 30)



Large Volume Scan



Diamond Large Volume Scan

VHP eTV Reconstructions

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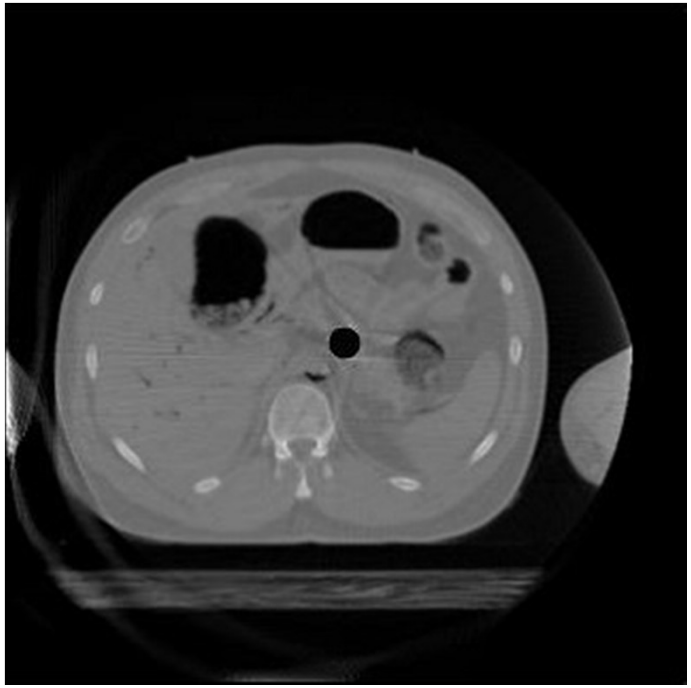
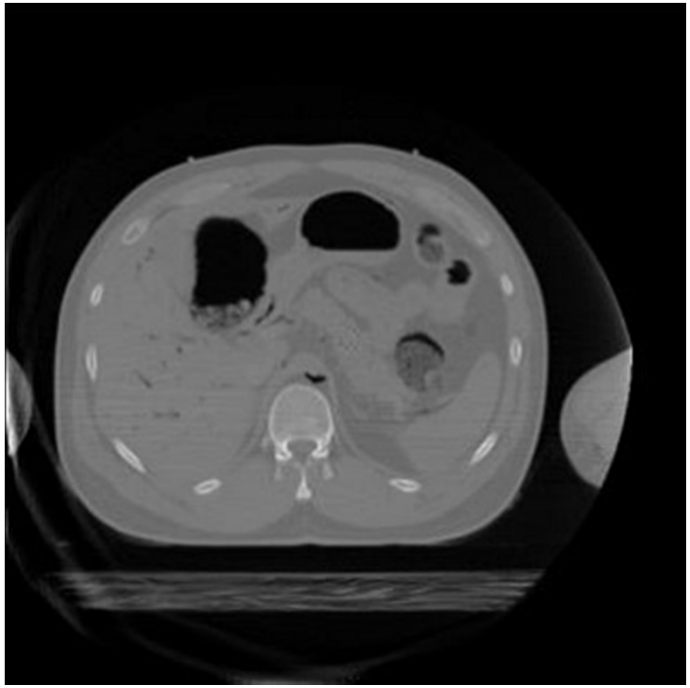
Outmost Slices (z=30 of 30)



Diamond Large Volume Scan



Helix Diamond Large Volume Scan

Discussion and Outlook

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- Coverage gain with presented method:
  - Short Scan 25 %, LVS: 27 % Helix: axial gain

- Reconstruction:
  - eTV lowers RMSE compared to SART by 29 %

But:

- Only coverage > 0.9 was considered
- Different detector settings may fit better
- Other eTV parameters may increase quality

Thank you very much for your attention