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

Stromer, Daniel
Pattern Recognition Lab (CS 5)
Outline

● Introduction

● Materials and Methods
  ● Scan Modes and Field-of-View Enlargement
  ● C-arm CT 3-D Reconstruction

● Results

● Discussion and Outlook
Introduction

- 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

- 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

- 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 $u$
     #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

1000 mm x 400 mm
Coverage Results

<table>
<thead>
<tr>
<th>Scan Mode</th>
<th>Radon sphere coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard [mm]</td>
</tr>
<tr>
<td>Short Scan</td>
<td>261</td>
</tr>
<tr>
<td>Large Volume Scan</td>
<td>475</td>
</tr>
<tr>
<td>Helix LVS</td>
<td>475</td>
</tr>
</tbody>
</table>

- 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

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

\[ p = R \cdot f(v) \]

- Minimization of objective function (SSD):

\[ \min \| R \cdot f(v) - p \|_2^2 \]

\( p \): measured data

\( R \): Radon transform

\( v \): voxel
SART Reconstruction

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

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

\[
\min \| \psi f(\nu) \|_1 \quad \text{subject to} \quad \min \| Rf(\nu) - p \|_2^2 < \epsilon
\]

- $\psi$ is a sparsifying transformation of $f(\nu)$
- $\epsilon$ denotes the raw data consistency (similarity measure)
Results
Configuration

- Visual Human Project data set

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

- Error measurement

\[ \text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (f_i(v) - \hat{f}_i(v))^2} \]

- Reconstructed with SART and eTV
Reconstruction Results

<table>
<thead>
<tr>
<th>Scan Mode</th>
<th>$RMSE_{SART}$</th>
<th>$RMSE_{eTV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Scan</td>
<td>0.2134</td>
<td>0.1370</td>
</tr>
<tr>
<td>Diamond Short Scan</td>
<td>0.2026</td>
<td>0.1242</td>
</tr>
<tr>
<td>Standard LVS</td>
<td>0.0608</td>
<td>0.0549</td>
</tr>
<tr>
<td>Diamond LVS</td>
<td>0.0322</td>
<td>0.0217</td>
</tr>
<tr>
<td>Helical LVS</td>
<td>0.0641</td>
<td>0.0488</td>
</tr>
<tr>
<td>Helical Diamond LVS</td>
<td>0.0229</td>
<td>0.0151</td>
</tr>
</tbody>
</table>

➢ $eTV$ lowers the RMSE compared to SART by 29.1 %
VHP eTV Reconstructions

Central Slices (z=15 of 30)

Large Volume Scan

Diamond Large Volume Scan
VHP eTV Reconstructions

Outmost Slices (z=30 of 30)

Diamond Large Volume Scan

Helix Diamond Large Volume Scan
Discussion and Outlook

- 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.

- **Standard Diamond**
- **LVS**
  - \( d = 471 \text{ mm} \)
  - \( d = 605 \text{ mm} \)
- **Short**
  - \( d = 261 \text{ mm} \)
  - \( d = 327 \text{ mm} \)