Improved C-arm Computed Tomography for the Early Diagnosis of Osteoarthritis

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Osteoarthritis and Imaging Modalities

- Degeneration of knee cartilage
- Symptoms: pain, stiffness
- Causes: trauma, infection, injury

- Current imaging modalities: MRI, Radiography
  - Patient in supine position
  - Measure narrowing of joint-space
  - Insensitive to early changes
Stress-Test of the Knee Joint

- Measure cartilage deformation under weight-bearing conditions
- Use C-arm CT with horizontal trajectory
- Patient standing or in squatting position
- Load simulated, e.g. by backpack
- Outcome: deformation vs. load curve
Reconstruction Challenges

- Limited rotation angle
- Increased patient motion
- Fast scans → low resolution + noise
- Evaluation of the reconstructed volumes (No ground truth)

Pros:
- Freely positionable
- Low-priced

Cons:
- Only 160° rotation angle
Super-Short-Scans

- Iterative methods popular for reconstructions from few views
- FBP is fast and well known

Short-Scan: \( \lambda \geq \pi + 2\delta_{max} \)
Super-Short-Scan: \( \lambda < \pi + 2\delta_{max} \)
Thanks for your attention
Methods
Redundancy Weights

- Redundant rays

\[ g(\delta, \lambda) = g(-\delta, \pi + \lambda + 2\delta) \]

Short-Scan: \( \lambda \geq \pi + 2\delta_{max} \)
Super-Short-Scan: \( \lambda < \pi + 2\delta_{max} \)
Compensation Weights

- Scan range: $\pi + \delta_x$
- Super-short-scan leads to missing data
- Compensate missing data by increasing the weight of spatially close rays
- Redundancy weights still needed
Compensation Weights
Bilateral Filtering

- Compensation weights can remove low-frequency bias
- Reconstruction still produces streaking artifacts and noise
- Solution: Apply bilateral filter after reconstruction

Geometric distance: \[ g_1(x', y') = g\left(\| (x', y')^T - (x, y)^T \|_2, \sigma_g \right) \]

Photometric distance: \[ g_2(x', y') = g(|f(x, y) - f(x', y')|, \sigma_p) \]

\[ f^{BF}(x, y) = \sum_{(x', y') \in N} g_1(x', y') \times g_2(x', y') \]
Reconstruction Pipeline

1. Precompute “compensation weights” based on geometry
2. Multiply projection data with “compensation weights”
3. Reconstruct using a conventional FBP approach
4. Apply bilateral filter on reconstructed data
Evaluation and Results
Evaluation

- Simulations using the Shepp-Logan phantom
- Geometrical setup
  - 640 detector elements of size 0.5mm
  - Source to detector distance 500mm
  - Fan angle $2\delta_{max} \approx 35.5^\circ$
  - 180 projections in a range of 180° (Short-Scan = 215.5°)

- 5 different reconstructions:
  - FBP using redundancy weights
  - FBP using redundancy weights + BF
  - Iterative with TV regularizer
  - FBP using compensation weights
  - FBP using compensation weights + BF
Qualitative Results
Qualitative Results – Line Profiles
## Quantitative Results

<table>
<thead>
<tr>
<th>Method</th>
<th>rRMSE</th>
<th>MSE</th>
<th>SSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redundancy</td>
<td>0.1301</td>
<td>0.0286</td>
<td>0.9528</td>
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<tr>
<td>Redundancy BF</td>
<td>0.1271</td>
<td>0.0273</td>
<td>0.9594</td>
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<tr>
<td>Compensation</td>
<td>0.0673</td>
<td>0.0076</td>
<td>0.9594</td>
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<tr>
<td>Compensation BF</td>
<td>0.0569</td>
<td>0.0055</td>
<td>0.9673</td>
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<tr>
<td>Iterative TV</td>
<td>0.0566</td>
<td>0.0054</td>
<td>0.9777</td>
</tr>
</tbody>
</table>

- **Error metrics:**
  - Mean-square-error (MSE)
  - Relative root mean-square-error (rRMSE)
  - Structural similarity index (SSIM)
Further Results: 160° scan range / 20° fan-angle
Summary / Outlook
Summary / Outlook

- We propose novel projection data weights, that consider:
  - redundant data
  - missing data
- The weights remove a low-frequency bias caused by missing data
- Bilateral filtering to remove high-frequency artifacts and noise
- Reconstruction results are comparable to iterative, TV regularized approach

- Future work:
  - Extend concept to cone-beam geometry
  - Evaluation on real data
References

Redundancy Weights

Super-Short Scan

Iterative vs. FBP
Thanks again for your attention! Questions?