Noise and Artifact Reduction in Flat Detector CT Perfusion Imaging

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Workshop on Iterative Reconstruction with Compressed Sensing
January, 20th 2014
1. Flat Detector CT Perfusion
2. Digital Brain Perfusion Phantom
3. Reconstruction & Noise Reduction
4. Numerical Study: Digital Brain Phantom
5. Clinical Patient Studies
Flat Detector CT Perfusion

- CT Perfusion (CTP) quantifies blood flow in brain for diagnosis of ischemic stroke
- New treatment options for stroke: catheter guided therapy in interventional room
- Flat Detector CTP: monitor perfusion before and during intervention using C-arm system

1. intra-venous contrast agent injection
2. (Flat Detector) CT scanning
3. image analysis to quantify blood flow
Scanning Protocols

Challenges:

- Low C-arm acquisition speed (3.6-5.5 s / 200° incl. pause)
- Angular under-sampling (133-248 projections / 200°)
- Low contrast-to-noise ratio in brain tissue (peak 5-30 HU)
- Patient motion
Scanning Protocols

• 5 s Protocol with bi-plane C-arm system
  • 2 Mask Rotations
  • 7 Bolus Rotations
  • 248 Projections / Rotation
  • 4.2 s / Rotation
  • 1 s Pause between Rotations

• 3 s Protocol with robotic C-arm system
  • 2 Mask Rotations
  • 10 Bolus Rotations
  • 133 Projections / Rotation
  • 2.6 s / Rotation
  • 1 s Pause between Rotations
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Dynamic Brain Phantom - Time Curves

Online available: http://www5.cs.fau.de/data
Dynamic Brain Phantom - Projection Data

- Full Projection Data with Tissue and Bone
- Subtracted Projection Data with Dynamic Contrast Enhancement
- Subtracted Projection Data with Dynamic Contrast Enhancement and Poisson Noise
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Flat Detector CT Perfusion

- FDK reconstruction of mask and bolus sweeps
- Rigid motion correction
- Mask subtraction
DynaCT Perfusion

- Noise & artifact reduction
- Time-contrast curve computation
- Perfusion parameter maps calculation
FDK-SR-JBF Algorithm for Flat Detector Perfusion CT

Noise Reduction by Joint Bilateral Filtering (JBF)
Noise Reduction: Bilateral Filtering

\[
I'(p) = \frac{\sum_{o \in N_p} I(p + o) \mathcal{W}(p, o)}{\sum_{o \in N_p} \mathcal{W}(p, o)}
\]

\[
\mathcal{G}_{\sigma}(x) = \exp \left(-0.5 \cdot \frac{\|x\|^2}{\sigma^2}\right)
\]

\[
\mathcal{W}(p, o) = \mathcal{G}_{\sigma_R} (I(p) - I(p + o)) \cdot \mathcal{G}_{\sigma_D}(p - o)
\]

Noise Reduction: Joint Bilateral Filtering (JBF)

\[ I'(p) = \frac{\sum_{o \in N_p} I(p + o)W_M(p, o)}{\sum_{o \in N_p} W_M(p, o)} \]

\[ W_M(p, o) = G_{\sigma_R}(M(p) - M(p + o)) \cdot G_{\sigma_D}(p - o) \]

Joint Bilateral Filtering: Perfusion Guidance Volume

Temporal maximum intensity projection (MIP):

$\text{MIP} = \max \text{Volume 1, Volume 2, Volume 10}$

3D Bilateral Filtering

Guidance MIP
Joint Bilateral Filtering for Flat Detector Perfusion

Volume 2

JBF

Volume 4

JBF

Volume 8

JBF

MIP (Guidance Volume)
FDK-SR-JBF Algorithm for Flat Detector Perfusion CT

Streak Artifact Reduction (SR)
Streak Artifact Detection in Guidance Image

Slice 63

Slice 100

MIP

Total Variation of MIP
Vessel/Streak Identification

![Graph showing contrast attenuation over time for Arterial TCC and Streak TCC. The graph peaks at a certain time indicating uptake μglobal.](image)

- Arterial TCC
- Streak TCC
Guidance Image Streak Identification

- Brain segmentation in air, bones and tissue

- Identify vessel & streaks by MIP thresholding and TCC analysis
  - negative MIP value in tissue -> streak
  - high MIP value in tissue:
    - TAC has single high uptake -> vessel
    - Otherwise -> streak

- Identify streaks by total variation of MIP
  - high total variation and no vessel -> streak
Guidance Image Streak Removal (SR)

- Bilateral filtering
- Streak smoothing
- Joint bilateral 3 Iterations
FDK-SR-JBF Algorithm

FDK reconstruction

Rigid motion compensation

Mask subtraction

Temporal MIP computation

Bilateral filtering of MIP

Joint bilateral filtering

Streaks identification

Smoothing of streaks in MIP

For $i = 1 \ldots N_{it}$

Joint bilateral filtering

Update guidance volume

Streak removal

Initial Denoising

Motion compensation & Reconstruction

Final denoising
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# Digital Brain Phantom - Quantitative Results

<table>
<thead>
<tr>
<th></th>
<th>Pearson Correlation</th>
<th>RMSE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>FDK-SR-JBF</td>
<td>OS-TV</td>
</tr>
<tr>
<td>CBF</td>
<td>0.83</td>
<td>0.84</td>
</tr>
<tr>
<td>CBV</td>
<td>0.74</td>
<td>0.75</td>
</tr>
<tr>
<td>MTT</td>
<td>0.85</td>
<td>0.89</td>
</tr>
<tr>
<td>TTP</td>
<td>0.87</td>
<td>0.86</td>
</tr>
<tr>
<td>Computation Time</td>
<td>69 s</td>
<td>1610 s</td>
</tr>
</tbody>
</table>
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Patient Study with Head Motion
3 s zeego Acquisition

Patient image data by courtesy of Dr. Struffert and Prof. Dörfler, Neuroradiology, Universitätsklinikum Erlangen

- 69 year old male
- Occlusion of the middle cerebral artery on the left
- The cerebral artery could be re-canalized successfully with self-expanding stents
Patient Study with Head Motion

(a) FDK-GAUSS  
(b) FDK-JBF  
(c) FDK-TIPS-3
January 20th 2014   |   Michael Manhart   |   Pattern Recognition Lab (CS 5)

axial

FDK-SR-JBF  OS-TV  FDK-SR-JBF  OS-TV

CBF

CBV
Patient Study with Pre and Post Treatment Scan
3 s zeego Acquisition

Patient image data by courtesy of Dr. Struffert and Prof. Dörfler, Neuroradiology, Universitätsklinikum Erlangen

- 72 year female patient
- Occlusion left vertebral artery, including the posterior inferior cerebellar artery
- The vertebral artery could be re-canalized successfully by mechanical recanalization therapy
(ax,cb)

(ax,ol)

(sa)
Patient Study with Pre and Post Treatment Scan 5 s bi-plane Acquisition

Patient image data by courtesy of Dr. Struffert and Prof. Dörfler, Neuroradiology, Universitätsklinikum Erlangen

- 87 year female patient
- Occlusion of the right distal carotid artery
- The carotid artery could be recanalized successfully by mechanical recanalization therapy
Flat Detector CT CBF & CBV Maps
Flat Detector CT MTT & TTP Maps

Pre Treatment

Post Treatment

MTT

TTP
Dynamic Angiography
Summary & Outlook

● Interventional perfusion imaging with flat detector CT in clinical practice is feasible

● FDK-SR-JBF approach for computational fast noise and streak artifact reduction

● Outlook:
  ● Improved streak identification using pattern recognition approaches
  ● Online motion correction
  ● Advanced analytic reconstruction
  ● Further validation with patient studies