Deep learning enhanced bilateral post-filtering of noisy PET data

Motivation

- PET images can exhibit high noise levels, which affects qualitative and quantitative evaluation, especially in respiratory gated or dynamic imaging.
- Gaussian post-filtering is routinely used to improve signal-to-noise ratio but degrades spatial resolution and reduces contrast recovery (CR) of small lesions.
- Edge-preserving bilateral filtering (BF) is able to overcome this shortcoming but requires careful tuning of two parameters \( \sigma_3 \) and \( \sigma_1 \) acting in the spatial and intensity domain, respectively [1]:

\[
W(m, n) = \exp \left( \frac{(P_m - P_n)^2}{2\sigma_3^2} \right) \cdot \exp \left( \frac{(I_m - I_n)^2}{2\sigma_1^2} \right)
\]

- Development of convolutional neural network (CNN) to replicate edge-preserving properties of BF.
- Potential to remove time-consuming manual tuning of BF parameters, thus facilitating application in clinical context.

Methods

- Used 280 volumes from 35 respiratory-gated PET/CT measurements (8 gates) to generate pairs of standard recon (STD) and manually BF-filtered images for CNN training.
- CNN based on 2D Residual UNet architecture (with long and short skip-connections) implemented in MXNet 1.9.0.
- Split data in 184 training and 40 validation image pairs for training and 56 reserved images for testing phase.
- Quantitative comparison of STD vs. BF vs. CNN images via percentage differences (pdiff):

\[
pdiff(a / b) = \frac{a - b}{(a + b) / 2} \times 100\%
\]

- Noise-level (SUV\(_{sd} / \text{SUV}_{mean}\)) pdiff of homogenous 3DROI (liver).
- Hot structure (SUV\(_{max}\)) pdiff of small 3D-ROI (e.g., lesion).
- Voxel-based correlation comparison (CNN vs. BF):

\[
\text{correlation coeff, voxel intensity correlation}
\]

Results

<table>
<thead>
<tr>
<th>a / b</th>
<th>hot structure pdiff</th>
<th>noise level pdiff</th>
<th>voxel intensity correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SUV(_{max})</td>
<td>SUV(<em>{sd} / \text{SUV}</em>{mean})</td>
<td>(r^2)</td>
</tr>
<tr>
<td>BF / STD</td>
<td>(-3.1 ± 5.0) %</td>
<td>(-63.9 ± 28.1) %</td>
<td>0.973 ± 0.031</td>
</tr>
<tr>
<td>CNN / STD</td>
<td>(2.3 ± 0.6) %</td>
<td>(-58.1 ± 19.6) %</td>
<td>0.980 ± 0.018</td>
</tr>
<tr>
<td>CNN / BF</td>
<td>(3.7 ± 4.2) %</td>
<td>(7.1 ± 19.2) %</td>
<td>0.994 ± 0.005</td>
</tr>
</tbody>
</table>

≈ 7 s constant processing time for CNN-based post-filtering of single PET volume compared to filter parameter-dependent processing time of = 3 s – 27 min for BF-based post-filtering.

Conclusions

- Results indicate that CNN-based post-filtering produces PET images comparable to manually tuned BF.
- Noise level and CR comparable in CNN and BF-filtered images.
- Short constant vs. long parameter-dependent processing times improves clinical usability of BF type post-filtering.
- Further training with more images from different PET scanners to potentially improve/generalize CNN filtering performance.
- Integration of the derived CNN into new respiratory motion compensation framework under way.