Deep learning enhanced bilateral post-filtering of noisy PET data

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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 σ_S and σ_I acting in the spatial and intensity domain, respectively [1]:

$$W(m,n) = \underbrace{\exp\left(-\frac{(P_m - P_n)^2}{2\sigma_S^2}\right)}_{\text{spatial domain}} \cdot \underbrace{\exp\left(-\frac{(I_m - I_n)^2}{2\sigma_I^2}\right)}_{\text{intensity domain}}$$

➡ Development of convolutional neuronal 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

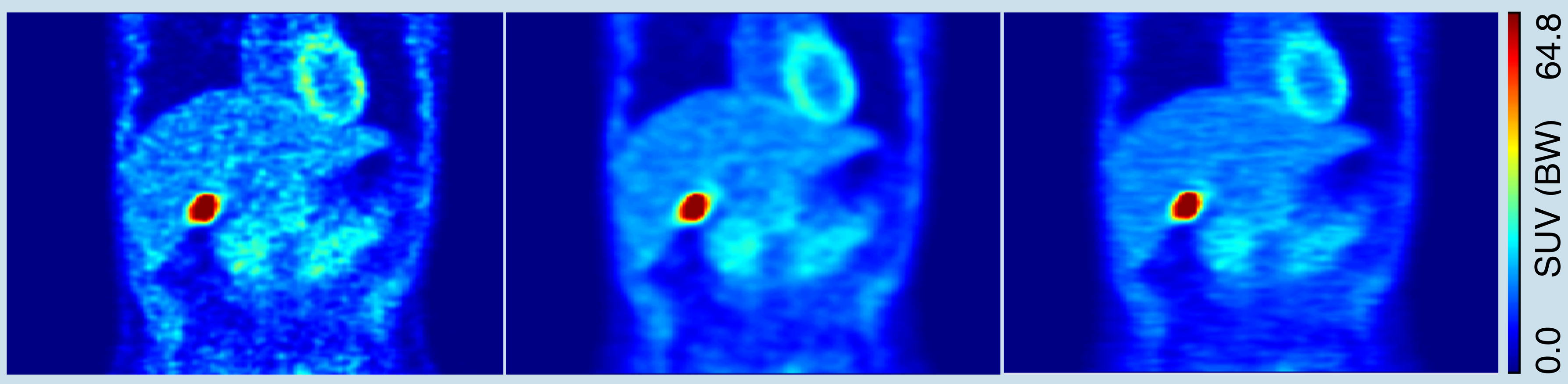
- Used 280 volumes from 35 respiratory-gated PET/CT measurements (8 gates) to generate pairs of standard recon (STD) and manually BF-filtered images for CNN training.
- CNN based on 2D Residual UNet architecture (with long and short skip-connections) implemented in MXNet 1.9.0
- Split data in 184 training 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*):

$$\text{pdiff}_{(a\,/\,b)} = \frac{a-b}{(a+b) \div 2} \times 100\,\%$$

  - noise-level (SUV_{sd} / SUV_{mean}) *pdiff* of homogenous 3D-ROI (liver).
  - hot structure (SUV_{max}) *pdiff* of small 3D-ROI (e.g. lesion).
- voxel-based correlation comparison (CNN vs. BF): *correlation coeff, voxel intensity correlation*

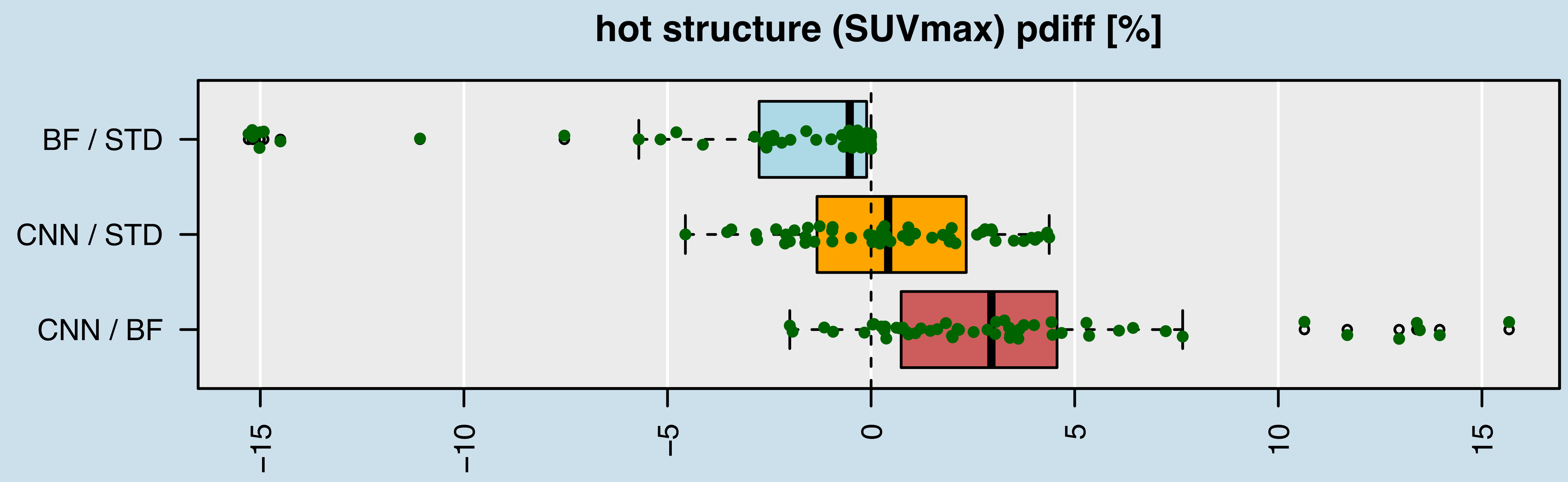
Results

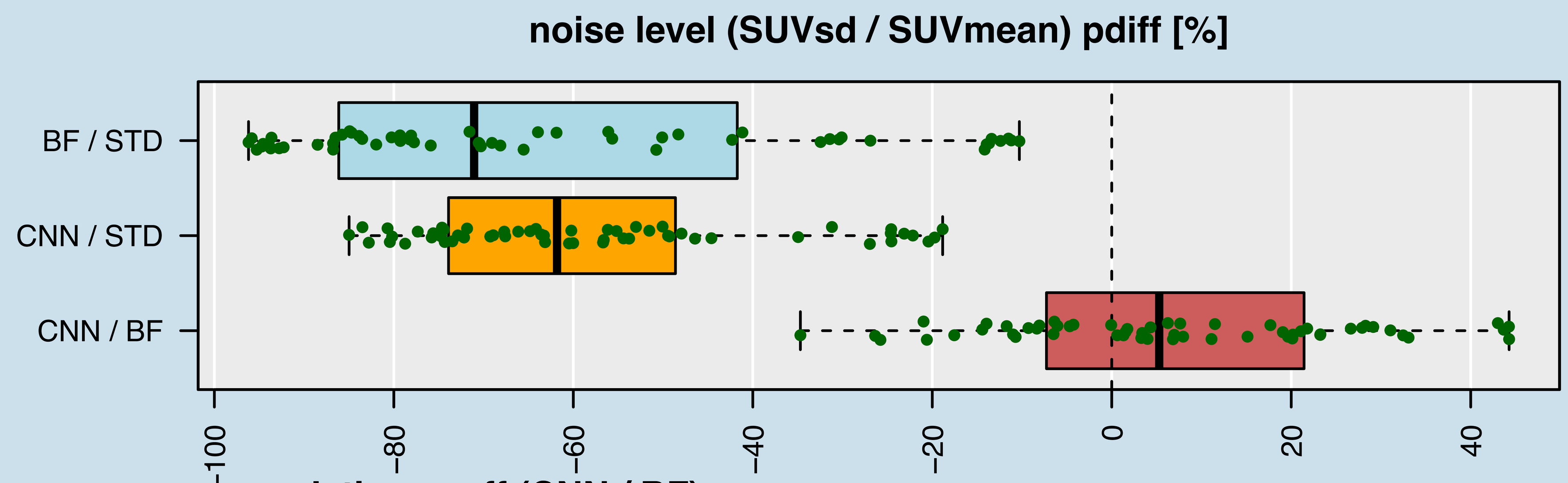
a / b	hot structure *pdiff* SUV_{max}	noise level *pdiff* SUV_{sd}/SUV_{mean}	voxel intensity *correlation coeff*
BF / STD	(-3.1 ± 5.0) %	(-63.9 ± 28.1) %	0.973 ± 0.031
CNN / STD	**(2.3 ± 0.6) %**	(-58.1 ± 19.6) %	0.980 ± 0.018
CNN / BF	**(3.7 ± 4.2) %**	**(7.1 ± 19.2) %**	**0.994 ± 0.005**

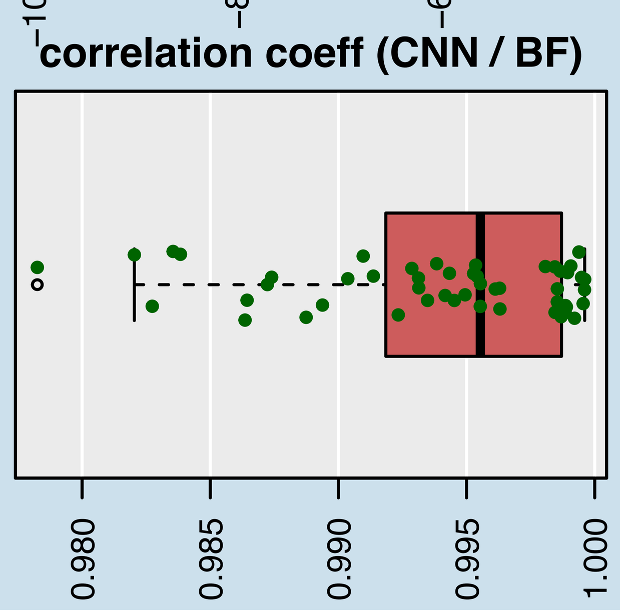


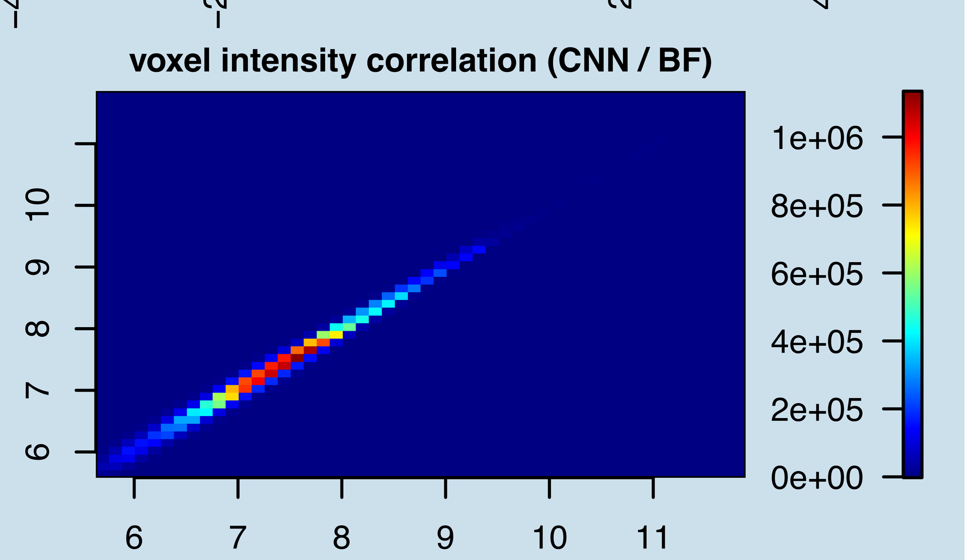
Standard Recon (STD) **BF filtered** (BF) **CNN filtered** (CNN)

- ≈ 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.

[1] F. Hofheinz, et al. *Suitability of bilateral filtering for edge-preserving noise reduction in PET.* EJNMMI Research 2011 1:23, doi: 10.1186/2191-219X-1-23