Low-dose CT Enhancement Network with a Perceptual Loss Function in the Spatial Frequency and Image Domains

Medical Imaging with Deep Learning 2020

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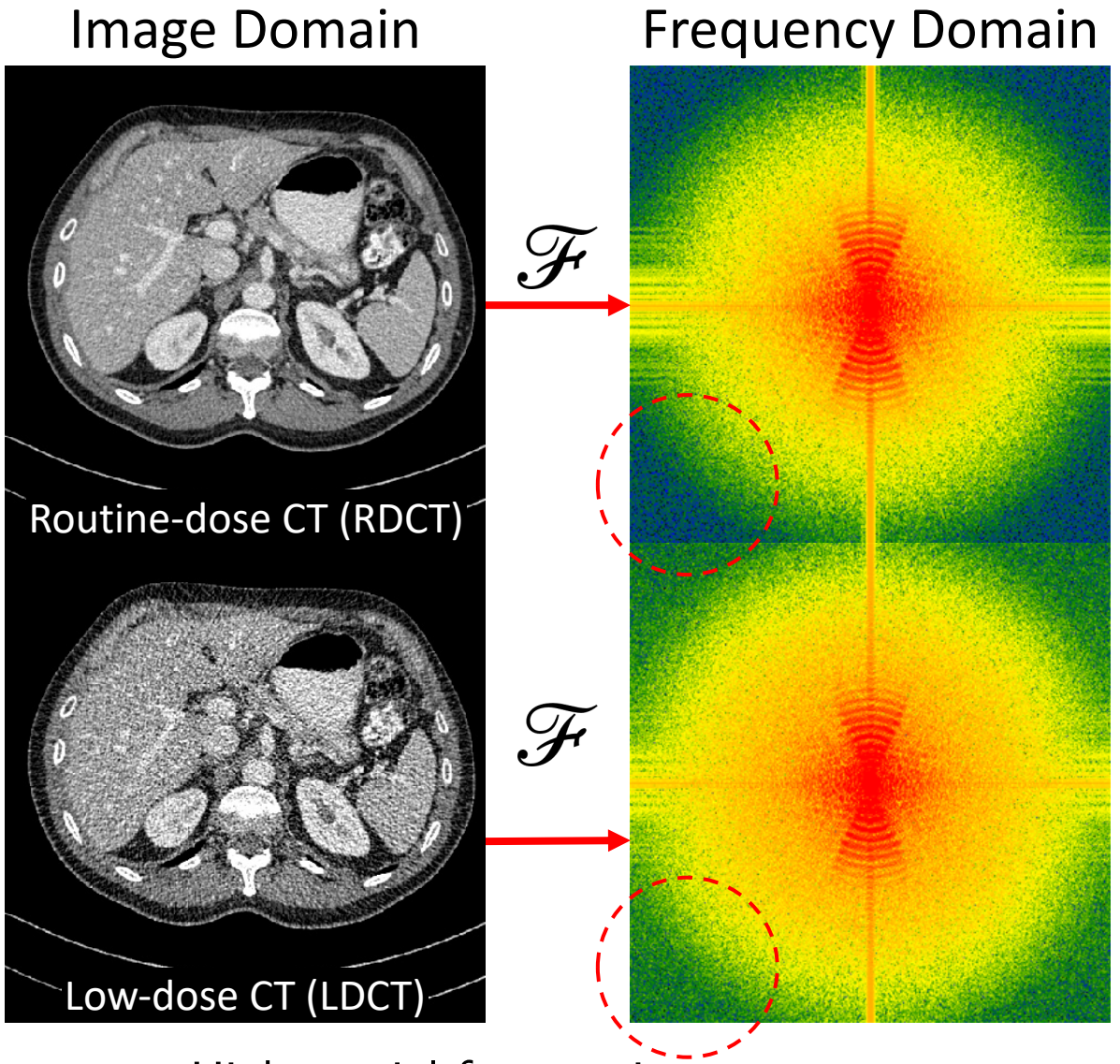
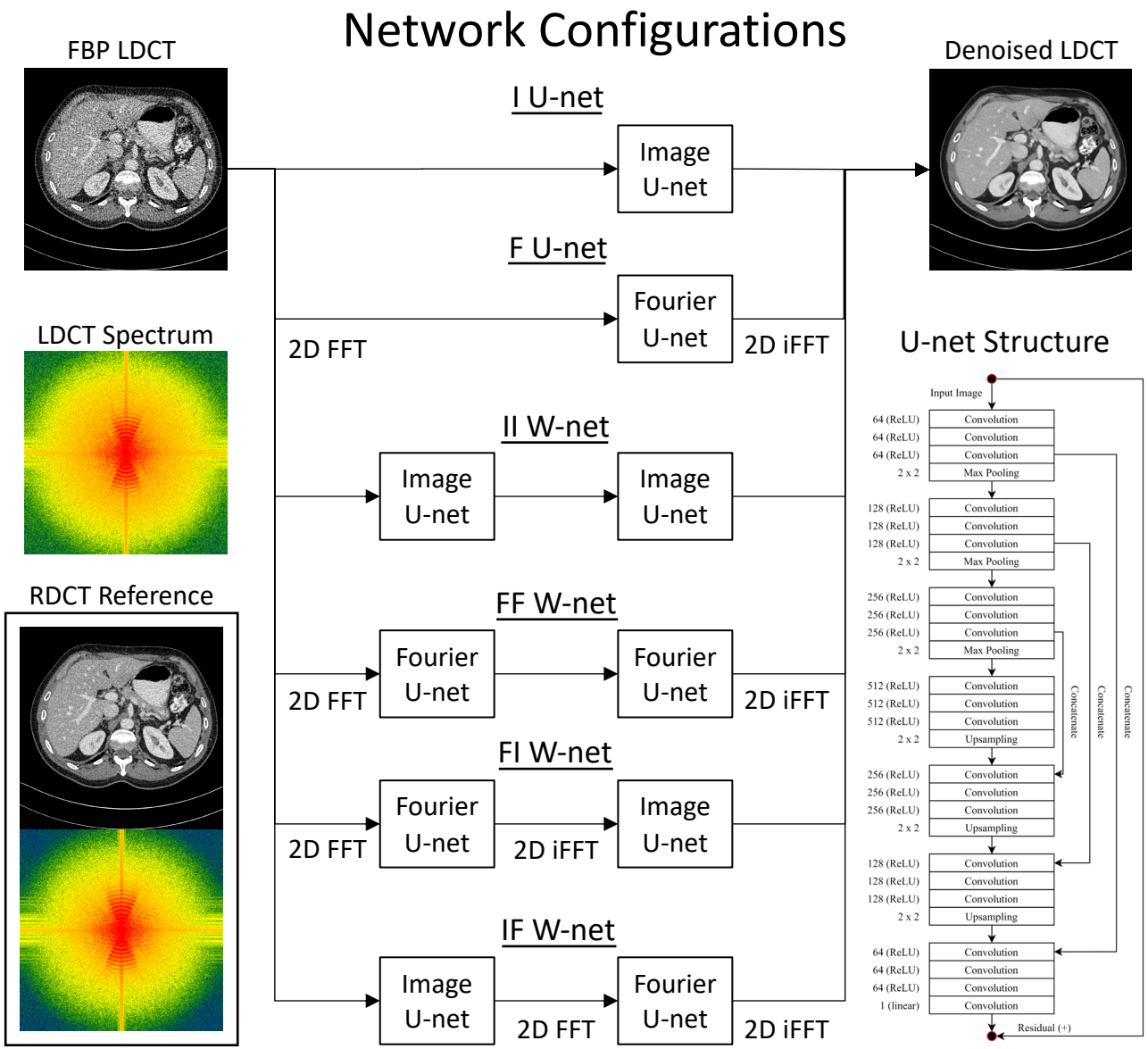
Low-dose Computed Tomography

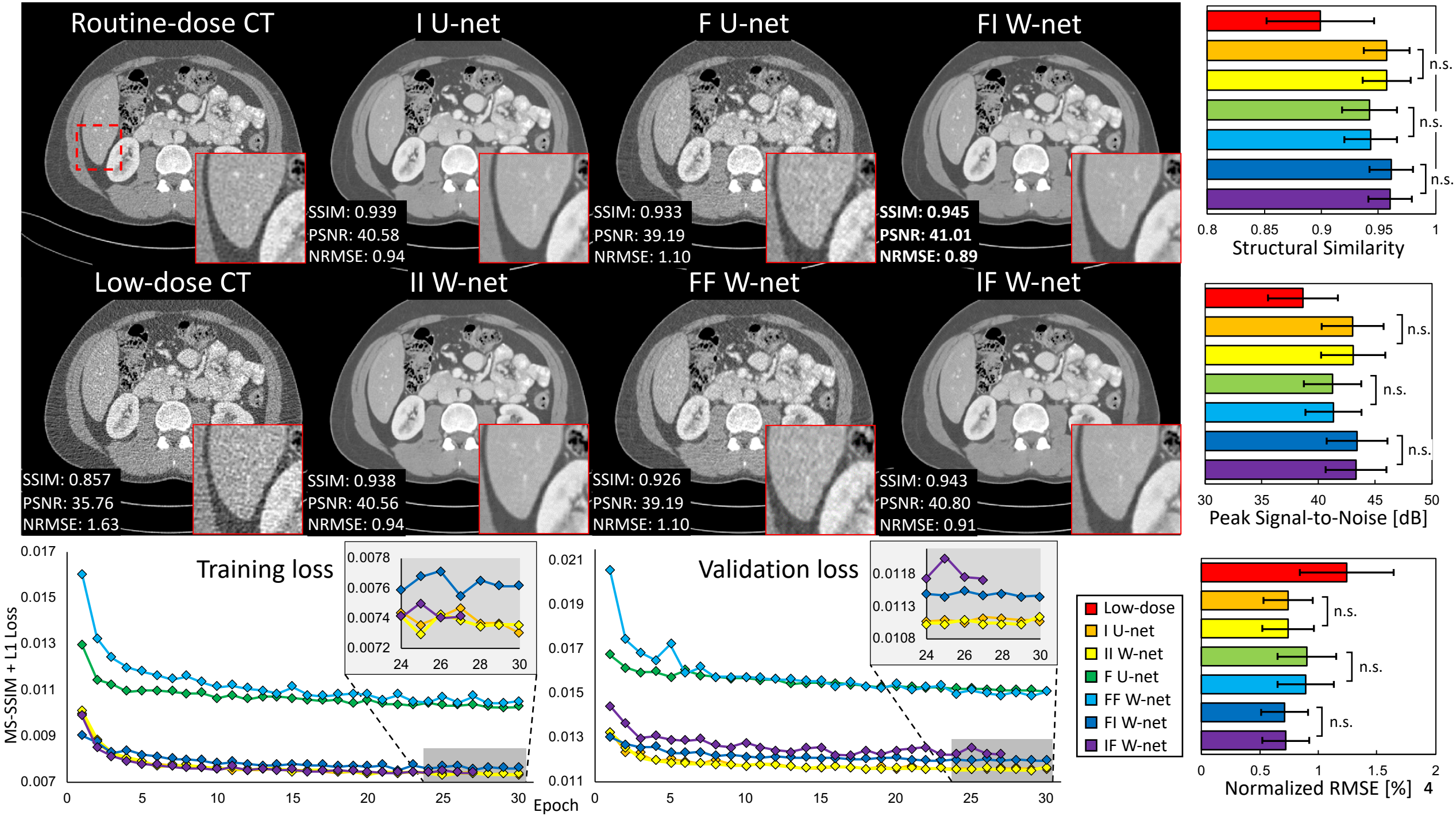
- Ionizing radiation dose from CT is a central consideration for safe imaging
- Low-dose CT increases noise and impedes the readability of the scan
- Iterative or deep learning reconstruction can improve signal-to-noise
- Real projection data is often proprietary and limits data for model development



Network Structures and Training Protocol



- Data from AAPM Low-dose CT Challenge
  - 5/2/3 patients training/validation/testing split (4,748/1,193/2,373 axial images)
  - Min-max normalization (0 to 1.0) of network inputs
- Trained end-to-end for 30 epochs using the Adam optimizer with a learning rate of 10^{-4}
- Early stopping of 10 and real-time data augmentation of training images to reduce model overfitting
- Loss function: weighted sum of multi-scale structural similarity and absolute error
- ~11.5m parameters per U-net


Routine-dose CT
I U-net
F U-net
FI W-net
SSIM: 0.939
PSNR: 40.58
NRMSE: 0.94
SSIM: 0.933
PSNR: 39.19
NRMSE: 1.10
SSIM: 0.945
PSNR: 41.01
NRMSE: 0.89
Low-dose CT
II W-net
FF W-net
IF W-net
SSIM: 0.857
PSNR: 35.76
NRMSE: 1.63
SSIM: 0.938
PSNR: 40.56
NRMSE: 0.94
SSIM: 0.926
PSNR: 39.19
NRMSE: 1.10
SSIM: 0.943
PSNR: 40.80
NRMSE: 0.91
n.s.
n.s.
n.s.
0.8
0.85
0.9
0.95
1
Structural Similarity
n.s.
n.s.
n.s.
30
35
40
45
50
Peak Signal-to-Noise [dB]
Training loss
Validation loss
MS-SSIM + L1 Loss
0.017
0.015
0.013
0.011
0.009
0.007
0.0078
0.0076
0.0074
0.0072
24
26
28
30
0.021
0.019
0.017
0.015
0.013
0.011
0.0118
0.0113
0.0108
0
5
10
15
20
25
30
Epoch
Low-dose
I U-net
II W-net
F U-net
FF W-net
FI W-net
IF W-net
n.s.
n.s.
n.s.
0
0.5
1
1.5
2
Normalized RMSE [%]

Discussion and Conclusions

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- Dual-domain approaches were quantitatively superior to single-domain U-nets and W-nets
  - Minimal qualitative differences between image-domain and dual-domain approaches
- Poor qualitative results of the spatial frequency domain networks were likely a result of optimizing the perceptual loss of the frequency spectrum
- Denoised images appear overly smoothed compared to routine-dose references and differ in noise characteristics
- Data quality and quantity is a limiting factor for denoising performance