## ADRN:Attention-Based Deep Residual Network for Hyperspectral Image Denoising

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- abundant spatial and spectral information
- Washington DC Mall image, 191 bands

• The goal of HSI denoising is to recover a clean image  ${\bf x}$  from a noisy observation  ${\bf y}$ ,

$$\mathbf{y} = \mathbf{x} + \mathbf{v}$$

- where  $\mathbf{v}$  is additive white Gaussian noise in general.
- To address this ill-posed inverse problem, some *prior knowledge* about x needs to be adopted.

- Non-local
  - BM4D
- Low-rank
  - LRTA, LRMR, LLRT
- Non-local and Low-rank
  - NG-Meet

### Time-consuming

Prior is hand-craft and thus lack of representation ability

- Deep-learning based method
  - HSID-CNN, SSGN

How to better capture both the spatial and spectral information?

How to design more discriminate network structure and improve the representation ability?



#### **Overall architecture**

- $Y_{spatial}$  denotes an input noisy band
- $Y_{spectral}$  denotes its K adjacent bands
- use auxiliary input to capture the low-rank property



#### **Overall architecture**

- extract the multi-scale spatial and spectral information
- concentrate on the most relevant feature



#### **Overall architecture**

- fuse the multi-level feature
- construct the residual noise



Multi-scale Feature Extraction Module

#### **Overall architecture**

$$R = F(\Theta, Y_{spatial}, Y_{spectral})$$
 $\hat{X} = Y_{spatial} - R$ 

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#### **Feature extraction block**



#### **Residual block**

- increases the flow of information
- contribute to noise prediction and back propagation



**Channel attention block** 

$$F_i = F_{i-1} + W_{CA} * X_i$$

$$X_i = W_2 * \delta(W_1 * F_{i-1})$$

 $W_{CA} = Sigmoid(W_4 * \delta(W_3 * GP(X_i)))$ 

• adaptively modulate feature representation

• The loss function of our training process consists of two parts:

$$L_{total} = \lambda L_{rec} + L_{reg}$$

•  $L_{rec}$  aims to ensure the restored result approximate to the ground truth:

$$L_{rec} = rac{1}{NHW}\sum_{i=1}^{N}||\hat{X}^i - X^i||_2^2$$

• while  $L_{reg}$  is used to enforce the residual noise satisfy a zeromean distribution:

$$L_{reg} = (rac{1}{NHW}\sum_{i=1}^{N}\sum_{h=1}^{H}\sum_{w=1}^{W}R_{hw}^{i})^{2}$$

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- Washington DC Mall image: 1280 imes 303 imes 191
- Normalize the gray values of each HSI band to [0,1] using ENVI software
- Select the middle 200 imes 200 for testing
- Crop 20  $\times$  20 patches from the remaining part and impose additive white Gaussian noise to formulate the training data

three types of noise are employed during test

- different bands have the same noise intensity,  $\sigma_n$  is set from 5 to 100
- the noise intensity of different bands conforms a random probability distribution, labeled as *rand(25)*
- for different bands, the noise intensity is also different but varies like a Gaussian distribution centered at the middle band, labeled as *Gau(200, 30)*

$$\sigma_n = eta \sqrt{rac{exp\{-(k-B/2)^2/2\eta^2\}}{\sum_{k=1}^B exp\{-(k-B/2)^2/2\eta^2\}}}$$

- K = 64,  $\lambda = 10$
- Adam with a batchsize of 382
- Use the truncated normal distribution to initialize the weights
- Learning rate starts from 1e-4 and decays exponentially every certain training steps (such as 5000)
- Roughly 300,000 iterations

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$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Noise Level	Criterion	LRTA [3]	BM4D [2]	LRMR [4]	HSID-CNN [7]	LLRT [5]	NG-Meet [6]	Proposed	
$ \sigma_n = 25 \qquad \frac{MSSIM}{\sigma_n} = 25 \qquad \frac{MPSNR}{0.9926 \pm 0.0002} = 0.9962 \pm 0.0001}{0.9932 \pm 0.0001} = 0.9932 \pm 0.0001} = 0.9968 \pm 0.0001}{0.9932 \pm 0.0001} = 0.9968 \pm 0.0001} = 0.9968 \pm 0.0001 = 0.9968 \pm 0.0001} = 0.9968 \pm 0.0001 = 0.9968 \pm 0.0001} = 0.9972 \pm 0.0001 = 0.9972 \pm 0.0001 = 0.9972 \pm 0.0001 = 0.9972 \pm 0.0001} = 0.9972 \pm 0.0001 = 0.9752 \pm 0.0001 = 0.9752 \pm 0.0001 = 0.9752 \pm 0.0001 = 0.9752 \pm 0.0001 = 0.9796 \pm 0.0001 = 0.9796 \pm 0.0001 = 0.9796 \pm 0.0001 = 0.9795 \pm 0.0001 = 0.9595 \pm 0.0001 = 0.9595 \pm 0.0001 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0002 = 0.9594 \pm 0.0001 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0001 = 0.9575 \pm 0.0002 = 0.9575 \pm 0.0001 $	$\sigma_n = 5$	MPSNR	$39.009 \pm 0.0034$	$41.188 \pm 0.0023$	$40.878 {\pm} 0.0036$	$41.684 {\pm} 0.0025$	$41.532 \pm 0.0054$	41.781±0.0052	$41.580 \pm 0.0043$	
$ \begin{aligned} \sigma_n &= 25 & \frac{\sigma_n = 25}{MSSIM} & \frac{0.9629 \pm 0.0002}{0.9685 \pm 0.0002} & \frac{0.9809 \pm 0.0001}{0.9809 \pm 0.0001} & \frac{0.9813 \pm 0.0001}{0.9862 \pm 0.0001} & \frac{0.9862 \pm 0.0001}{0.9880 \pm 0.0001} & \frac{0.9902 \pm 0.0001}{0.9902 \pm 0.0001} \\ \sigma_n &= 50 & \frac{MPSNR}{26.832 \pm 0.0052} & \frac{26.752 \pm 0.0034}{26.752 \pm 0.002} & \frac{28.806 \pm 0.0043}{28.968 \pm 0.0039} & \frac{30.759 \pm 0.0115}{31.669 \pm 0.0139} & \frac{31.669 \pm 0.0139}{32.070 \pm 0.0010} \\ \sigma_n &= 75 & \frac{MPSNR}{24.682 \pm 0.0054} & \frac{24.261 \pm 0.0035}{24.261 \pm 0.0035} & \frac{26.306 \pm 0.0046}{26.753 \pm 0.001} & \frac{26.752 \pm 0.0001}{0.9752 \pm 0.0001} & \frac{0.9752 \pm 0.0001}{0.9752 \pm 0.0001} & \frac{0.9762 \pm 0.0001}{0.9752 \pm 0.0001} & \frac{0.9762 \pm 0.0001}{0.9752 \pm 0.0001} & \frac{0.9752 \pm 0.0001}{0.9973 \pm 0.0001} & \frac{0.9752 \pm 0.0023}{0.9973 \pm 0.0002} & \frac{0.9752 \pm 0.0023}{0.9974 \pm 0.0033} & \frac{0.9752 \pm 0.0023}{0.9974 \pm 0.0033} & \frac{0.9752 \pm 0.0023}{0.9974 \pm 0.0033} & \frac{0.9752 \pm 0.0023}{0.9974 \pm 0.$		MSSIM	$0.9926 \pm 0.0002$	$0.9962 \pm 0.0001$	$0.9952 {\pm} 0.0001$	$0.9966 \pm 0.0001$	$0.9968 \pm 0.0001$	$0.9966 \pm 0.0001$	$0.9972{\pm}0.0001$	
$ \sigma_n = 50 \qquad \frac{\text{MPSNR}}{\sigma_n = 75} \qquad \frac{\text{MPSNR}}{\sigma_n = 100} \qquad \frac{\text{MPSNR}}{\sigma_n = rand(25)} \qquad \frac{26.32\pm0.002}{\text{MPSNR}} \qquad 26.832\pm0.002 \qquad 0.983\pm0.002 \qquad 0.9836\pm0.001 \qquad 0.9313\pm0.0001 \qquad 0.9382\pm0.001 \qquad 0.9752\pm0.001 \qquad 0.9752\pm0.001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9752\pm0.001 \qquad 0.9752\pm0.001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9796\pm0.0001 \qquad 0.9765\pm0.001 \qquad 0.9752\pm0.001 \qquad 0.9752\pm0.001 \qquad 0.9796\pm0.0001 \qquad 0.9765\pm0.0001 \qquad 0.9673\pm0.0001 \qquad 0.9555\pm0.0002 \qquad 0.9594\pm0.0001 \qquad 0.9673\pm0.0001 \qquad 0.9673\pm0.0001 \qquad 0.9555\pm0.0002 \qquad 0.9594\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9535\pm0.0002 \qquad 0.9594\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9535\pm0.0002 \qquad 0.9514\pm0.0011 \qquad 0.9535\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0001 \qquad 0.9535\pm0.0002 \qquad 0.9515\pm0.0001 \qquad 0.9535\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9515\pm0.0001 \qquad 0.9917\pm0.0004 \qquad 0.9515\pm0.0001 \qquad 0.9917\pm0.0005 \qquad 0.9515\pm0.0$	$\sigma_n = 25$	MPSNR	$30.672 \pm 0.0033$	$31.136 \pm 0.0025$	$33.029 \pm 0.0023$	$33.050 \pm 0.0028$	$34.701 \pm 0.0097$	$35.366 \pm 0.0094$	35.527±0.0104	
$ \sigma_n = 50 \qquad $		MSSIM	$0.9629 \pm 0.0002$	$0.9685 {\pm} 0.0002$	$0.9809 \pm 0.0001$	$0.9813 \pm 0.0001$	$0.9862 {\pm} 0.0\ 001$	$0.9880 \pm 0.0001$	0.9902±0.0001	
$ \frac{M}{\sigma_n = 75} \qquad \frac{M}{M} \frac{0.9243 \pm 0.001}{M} = \frac{0.9203 \pm 0.002}{0.9203 \pm 0.002} = \frac{0.9332 \pm 0.001}{0.9332 \pm 0.001} = \frac{0.9332 \pm 0.001}{0.9332 \pm 0.001} = \frac{0.9732 \pm 0.001}{0.9732 \pm 0.001} = \frac{0.9732 \pm 0.001}{0.9673 \pm 0.001} = \frac{0.9732 \pm 0.001}{0.9955 \pm 0.0001} = \frac{0.9732 \pm 0.001}{0.9955 \pm 0.0001}$	$\sigma_n = 50$	MPSNR	$26.832 \pm 0.0052$	$26.752 \pm 0.0034$	$28.806 \pm 0.0043$	$28.968 \pm 0.0039$	$30.759 \pm 0.0115$	$31.669 \pm 0.0139$	32.070±0.0102	
$ \sigma_n = 75 \qquad $		MSSIM	$0.9246 \pm 0.0001$	$0.9208 {\pm} 0.0002$	$0.9532 {\pm} 0.0001$	$0.9536 {\pm} 0.0001$	$0.9705 {\pm} 0.0001$	$0.9752 \pm 0.0001$	0.9796±0.0001	
$ \frac{\sigma_n = 100}{\sigma_n = rand(25)} \frac{MPSNR}{MSSIM} = \frac{28.200\pm0.0001}{0.9383\pm0.0001} = \frac{0.9192\pm0.0001}{0.9192\pm0.0001} = \frac{0.9273\pm0.0001}{0.9273\pm0.0001} = \frac{0.9323\pm0.0002}{0.9323\pm0.0002} = \frac{0.9394\pm0.0001}{0.9394\pm0.0001} = \frac{0.9673\pm0.0001}{0.9673\pm0.0001} = \frac{0.9673\pm0.0001}{0.9673\pm0.0001} = \frac{0.9673\pm0.0001}{0.9673\pm0.0001} = \frac{0.9673\pm0.0001}{0.9673\pm0.0001} = \frac{0.9673\pm0.0001}{0.9535\pm0.0001} = \frac{0.9673\pm0.0001}{0.9454\pm0.0003} = \frac{0.9673\pm0.0001}{0.9673\pm0.0001} = \frac{0.9673\pm0.0001}{0.9535\pm0.0002} = \frac{0.9394\pm0.0001}{0.9454\pm0.0001} = \frac{0.9673\pm0.0001}{0.9535\pm0.0002} = \frac{0.9394\pm0.0001}{0.9535\pm0.0001} = \frac{0.9673\pm0.0001}{0.9454\pm0.0003} = \frac{0.9673\pm0.0001}{0.9454\pm0.0003} = \frac{0.9673\pm0.0001}{0.9933\pm0.0002} = \frac{0.9973\pm0.0001}{0.991\pm0.0001} = \frac{0.9673\pm0.0001}{0.9454\pm0.0001} = \frac{0.9673\pm0.0001}{0.9535\pm0.0001} = \frac{0.9673\pm0.0001}{0.9454\pm0.0001} = \frac{0.9673\pm0.0001}{0.9916\pm0.0001} = \frac{0.9673\pm0.0001}{0.9916\pm0.0001} = \frac{0.9673\pm0.0001}{0.9914\pm0.0001} = \frac{0.9673\pm0.0001}{0.9917\pm0.0004} = \frac{0.9673\pm0.0001}{0.9914\pm0.0001} = \frac{0.9673\pm0.0001}{0.9914\pm0.0001} = \frac{0.9673\pm0.0001}{0.9914\pm0.0001} = \frac{0.9673\pm0.0001}{0.9914\pm0.0001} = \frac{0.9673\pm0.0001}{0.9914\pm0$	$\sigma_n = 75$	MPSNR	$24.682 \pm 0.0054$	$24.261 \pm 0.0035$	$26.306 \pm 0.0046$	$26.753 \pm 0.0039$	$28.385 \pm 0.0134$	29.116±0.0147	29.862±0.0175	
$ \sigma_n = 100 \qquad \qquad$		MSSIM	$0.8866 {\pm} 0.0001$	$0.8670 \pm 0.0001$	$0.9192 {\pm} 0.0001$	$0.9273 \pm 0.0001$	$0.9525 \pm 0.0002$	$0.9594 \pm 0.0001$	0.9673±0.0001	
$ \sigma_n = rand(25) $ $ \frac{\text{MPSNR}}{\text{MSSIM}} \begin{array}{c} 0.3494 \pm 0.0003 \\ 0.3494 \pm 0.0003 \\ 0.3119 \pm 0.0002 \\ 0.8199 \pm 0.002 \\ 0.8799 \pm 0.0002 \\ 0.8799 \pm 0.0002 \\ 0.9014 \pm 0.0001 \\ 0.9014 \pm 0.0001 \\ 0.9232 \pm 0.0001 \\ 0.9328 \pm 0.0001 \\ 0.9434 \pm 0.0001 \\ 0.9331 \pm 0.0001 \\ 0.9833 \pm 0.0002 \\ 0.9856 \pm 0.0001 \\ 0.9916 \pm 0.0001 \\ 0.9916 \pm 0.0001 \\ 0.9718 \pm 0.0275 \\ 0.9904 \pm 0.0001 \\ 0.9904 \pm 0.0001 \\ 0.9917 \pm 0.0004 \\ $	$\sigma_n = 100$	MPSNR	$23.175 \pm 0.0048$	$22.577 \pm 0.0054$	$24.310 \pm 0.0047$	$25.296 \pm 0.0043$	$26.712 \pm 0.0145$	$27.756 \pm 0.0083$	28.239±0.0176	
$\frac{\sigma_n = rand(25)}{MSSIM} \underbrace{MSSIM}_{0.9331\pm0.0001} \underbrace{0.9833\pm0.0002}_{0.9835\pm0.0002} \underbrace{0.9856\pm0.0001}_{0.9916} \underbrace{0.9916}_{\pm0.0001} \underbrace{0.9718\pm0.0275}_{0.9904\pm0.0001} \underbrace{0.9917\pm0.0004}_{0.9917\pm0.0004} \underbrace$		MSSIM	$0.8494 \pm 0.0003$	$0.8119 \pm 0.0002$	$0.8799 \pm 0.0002$	$0.9014 \pm 0.0001$	$0.9328 {\pm} 0.0001$	$0.9454 \pm 0.0001$	0.9535±0.0002	
$\frac{1}{2} = C_{222}(200, 20) + \frac{\text{MPSNR}}{28.200 \pm 0.0023} = 34.109 \pm 0.0037 = 35.962 \pm 0.0025 = 36.804 \pm 0.0029 = 28.635 \pm 0.0019 = 35.402 \pm 0.0053 = 37.722 \pm 0.0080$	$\sigma_n = rand(25)$	MPSNR	$28.843 \pm 0.0025$	$34.424 \pm 0.0034$	$36.094 \pm 0.0033$	$37.367 \pm 0.0028$	$34.360 \pm 2.6908$	$36.040 \pm 0.3682$	37.301±0.1633	
$\sigma = C_{au}(200, 20)$		MSSIM	$0.9331 {\pm} 0.0001$	$0.9833 {\pm} 0.0002$	$0.9856 {\pm} 0.0001$	$0.9916 \pm 0.0001$	$0.9718 {\pm} 0.0275$	$0.9904 \pm 0.0001$	0.9917±0.0004	
$\sigma_n = Gau(200, 30) \xrightarrow{\text{MSSIM}} 0.9119 \pm 0.0002  0.9794 \pm 0.0001  0.9893 \pm 0.0001  0.9895 \pm 0.0001  0.9094 \pm 0.000  0.9894 \pm 0.0001  0.9929 \pm 0.0001$	$\sigma_n = Gau(200, 30)$	MPSNR	$28.200 \pm 0.0023$	$34.109 \pm 0.0037$	$35.962 \pm 0.0025$	$36.804 \pm 0.0029$	$28.635 \pm 0.0019$	$35.402 \pm 0.0053$	$37.722 \pm 0.0080$	
		MSSIM	$0.9119 \pm 0.0002$	$0.9794 \pm 0.0001$	$0.9893 \pm 0.0001$	$0.9895 \pm 0.0001$	$0.9094 \pm 0.000$	$0.9894 \pm 0.0001$	0.9929±0.0001	

Table 1. Quantitative performance comparison of the denoising results



(a) Clean image (b) HSID-CNN 25.635/0.9235 (c) LLRT 26.644/0.9287 (d) NG-Meet 27.667/0.9442 (e) Proposed 28.233/0.9536

#### $\sigma_n = 100, Washington \ DC \ Mall$



(a) Clean image (b) HSID-CNN 36.295/0.9927 (c) LLRT 33.857/0.9764 (d) NG-Meet 36.434/0.9912(e) Proposed 37.333/0.9914

 $\sigma_n = Gau(200, 30), Washington DC Mall$ 

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# Thanks ! Any Questions?

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