

RSHazeDiff: A Unified Fourier-aware Diffusion Model for Remote Sensing Image Dehazing

TITS2024

传统方法：依赖物理先验（如暗通道先验），在复杂场景下易失效，导致颜色失真和伪影

扩散模型（DDPM）：在噪声估计阶段缺乏图像级约束，导致去雾结果出现内容混乱

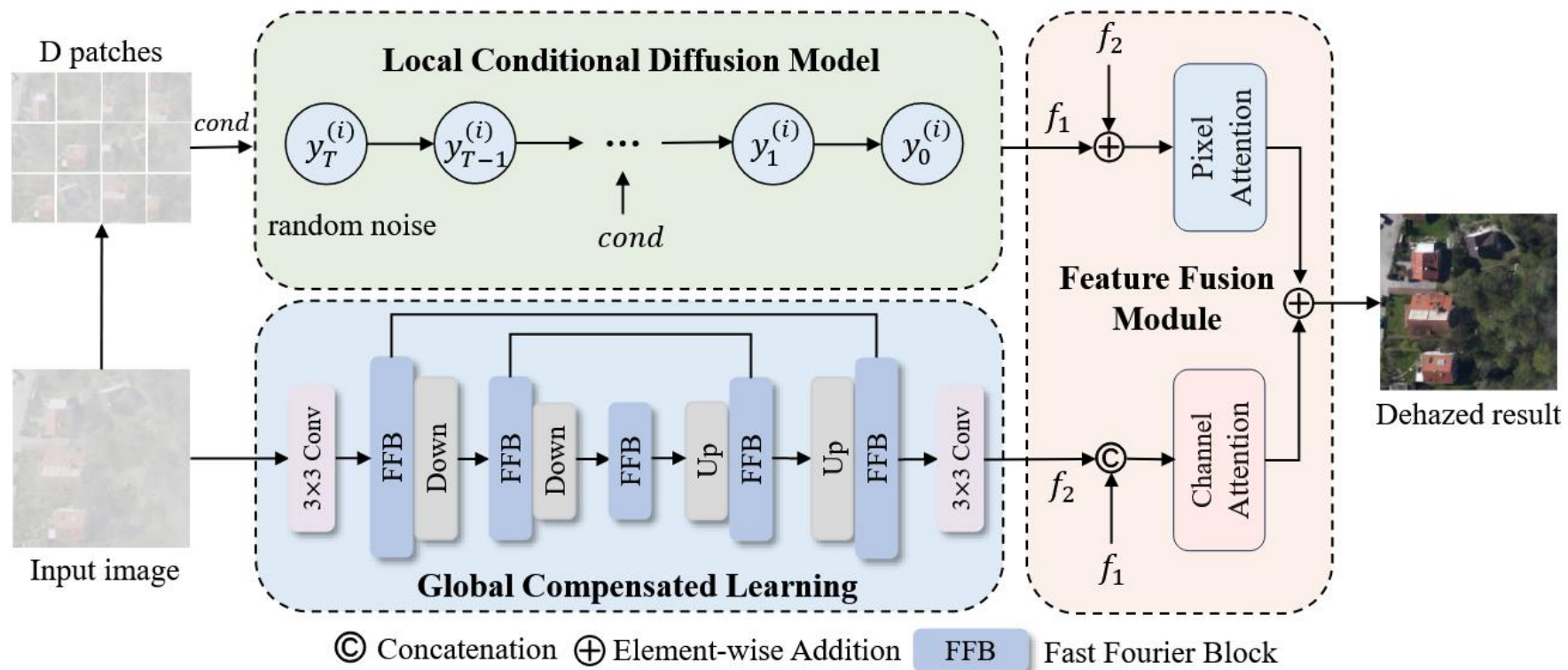
分块处理：忽略全局依赖，产生边界伪影

傅里叶感知迭代细化模块（FIR）：前向迭代过程中挖掘颜色和语义信息

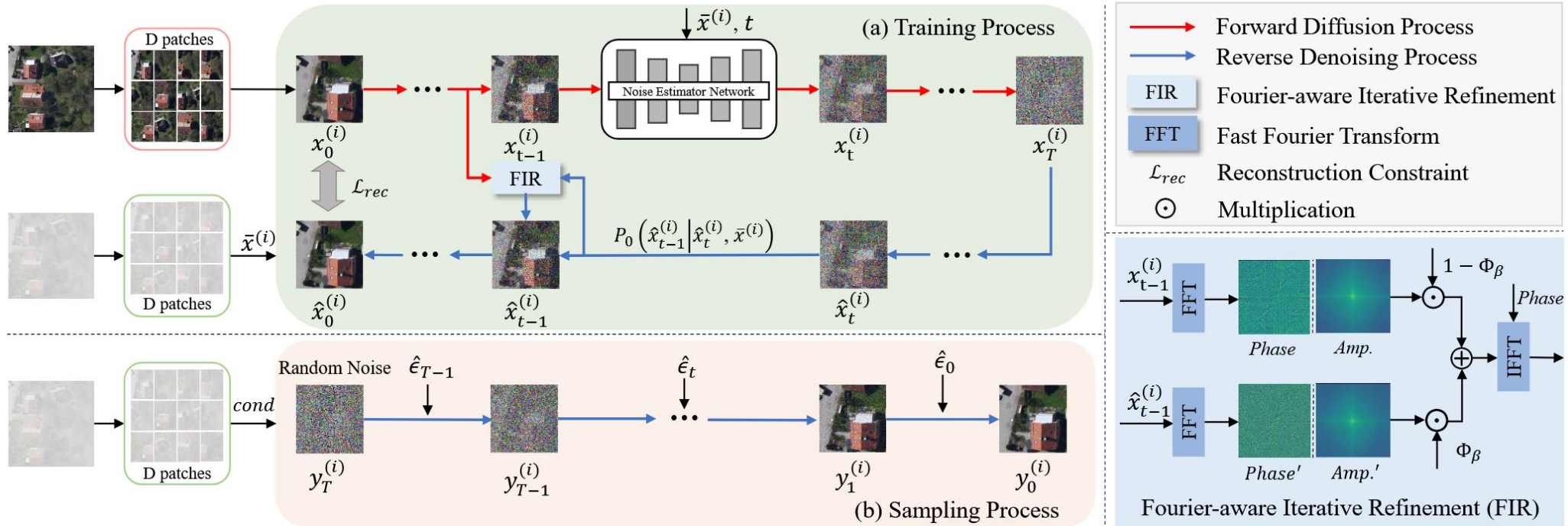
—————→ **分阶段的训练策略**：解决简单的噪声估计约束导致的内容不一致问题

全局补偿学习模块：消除基于补丁的图像处理方案中明显的块伪影

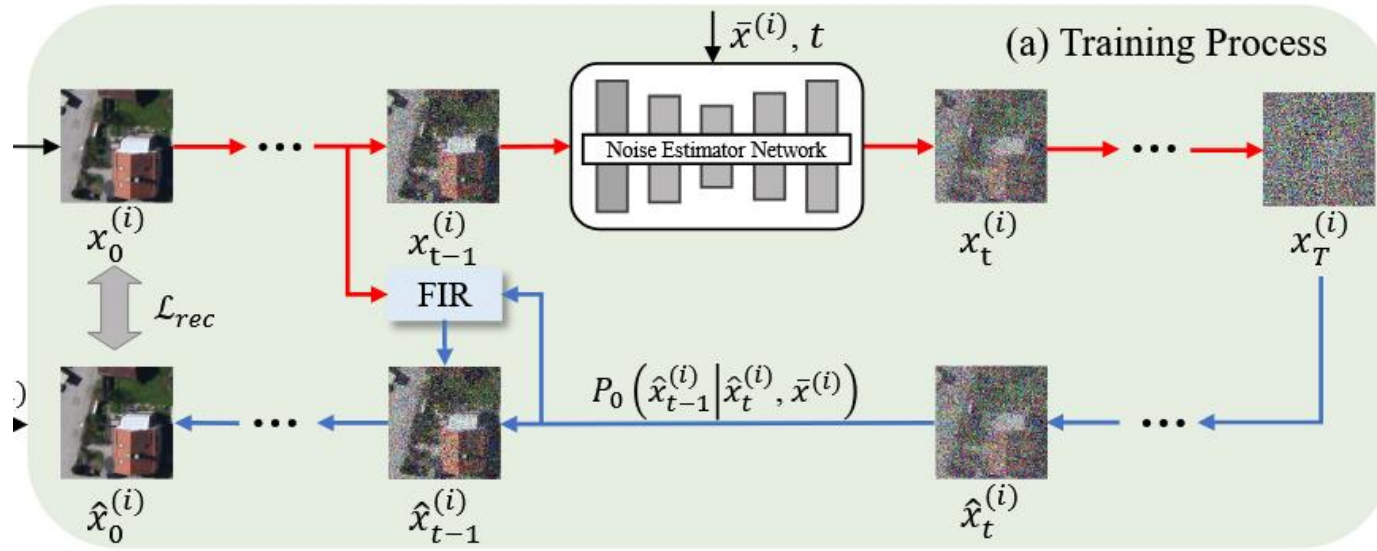
Method



Local Conditional Diffusion Model



Training Process



Algorithm 1 The training process of Fourier-aware conditional diffusion model

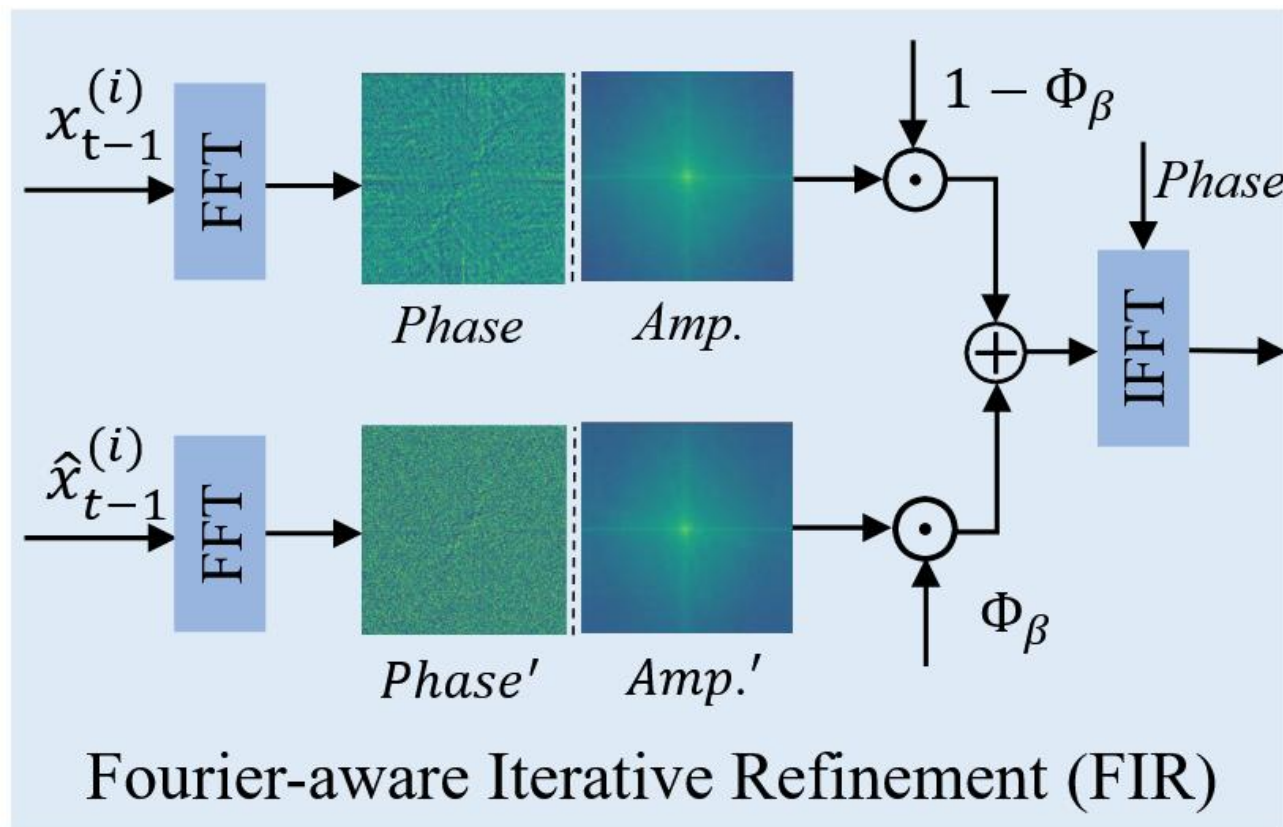
Input: Clean image x_0 , hazy image conditioner \bar{x} , denoiser network $\epsilon_\theta(x_t, \bar{x}, t)$, a random binary patch mask \mathbf{P}_i , transitional iteration M , number of implicit sampling steps S , time steps T , and the mask Φ_β in FIR module.

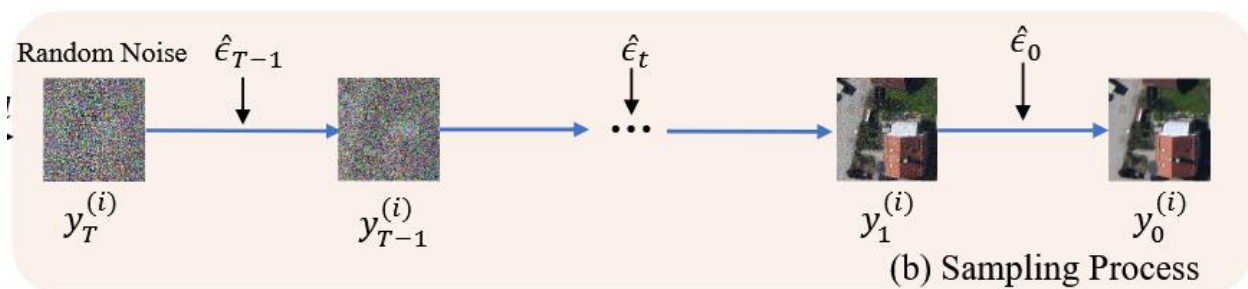
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1: while Not converged do
2:    $x_0^{(i)} = \text{Crop}(\mathbf{P}_i \circ x_0)$  and  $\bar{x}^{(i)} = \text{Crop}(\mathbf{P}_i \circ \bar{x})$ 
3:    $t \sim \text{Uniform}\{1, \dots, T\}$ 
4:    $\epsilon_t \sim \mathcal{N}(0, \mathbf{I})$ 
5:   if Current iterations  $\leq M$  then
6:     Take gradient descent step on
7:        $\nabla_\theta \left\| \epsilon_t - \epsilon_0 \left( \sqrt{a_t} x_0^{(i)} + \sqrt{1 - a_t} \epsilon_t, \bar{x}^{(i)}, t \right) \right\|^2$ 
8:   else
9:      $\hat{x}_{t_S}^{(i)} \sim \mathcal{N}(0, \mathbf{I})$ 
10:    for  $j = S : 1$  do
11:       $t = (j - 1) \cdot T/S + 1$ 
12:       $t_{next} = (j - 2) \cdot T/S + 1$  if  $j > 1$  else 0
13:       $\hat{\epsilon}_t = \epsilon_\theta(\hat{x}_t^{(i)}, \bar{x}^{(i)}, t)$ 
14:       $x_{t_{next}}^{(i)} = \sqrt{a_{t_{next}}} x_0^{(i)} + \sqrt{1 - a_{t_{next}}} \hat{\epsilon}_{t_{next}}$ 
15:       $\hat{x}_{t_{next}}^{(i)} = \sqrt{\alpha_{t_{next}}} \left( \frac{\hat{x}_t^{(i)} - \sqrt{1 - \alpha_t} \cdot \hat{\epsilon}_t}{\sqrt{\alpha_t}} \right) + \sqrt{1 - \alpha_{t_{next}}} \cdot \hat{\epsilon}_t$ 
16:       $\hat{x}_{t_{next}}^{(i)} = \text{FIR} \left( x_{t_{next}}^{(i)}, \hat{x}_{t_{next}}^{(i)}, \Phi_\beta \right)$ 
17:    end for
18:    Take gradient descent step on  $\nabla_\theta \mathcal{L}_{rec} \left( \hat{x}_0^{(i)}, x_0^{(i)} \right)$ 
19:  end if
20: end while
21: return  $\theta$ 

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Training Process



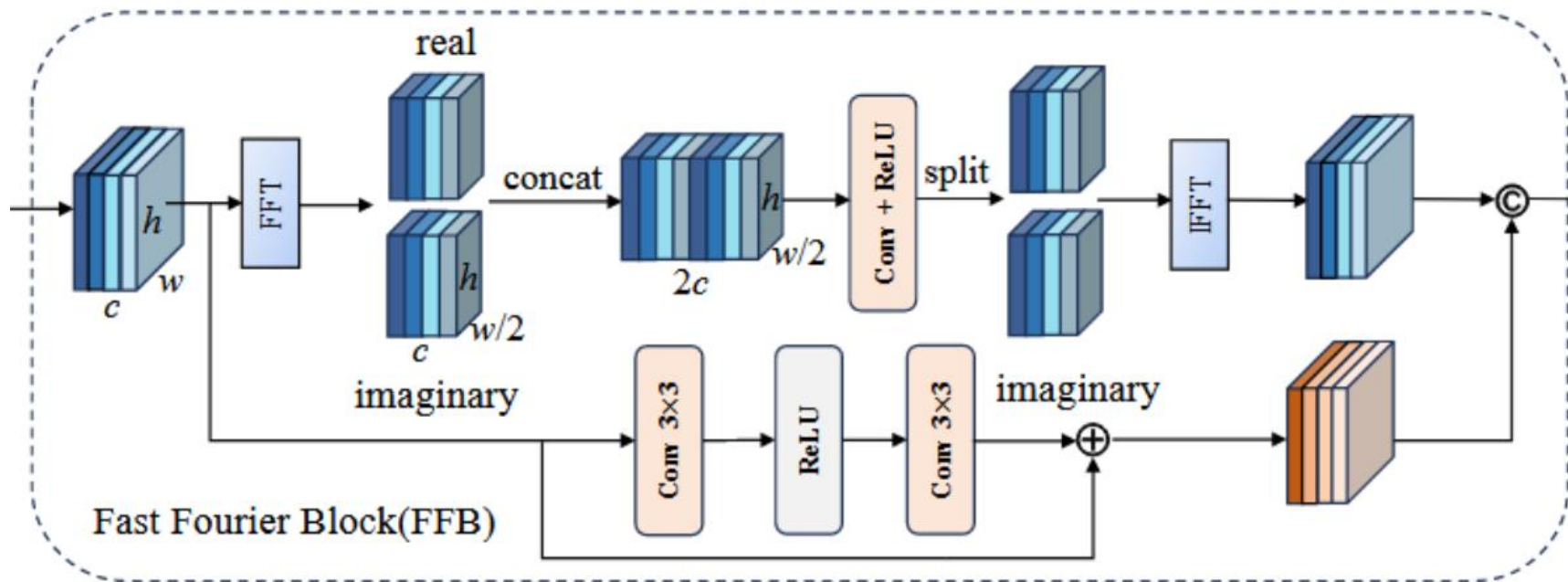


Algorithm 2 The sampling process of Fourier-aware conditional diffusion model

Input: Hazy image \bar{x} , $\epsilon_\theta(y_t, \bar{x}, t)$, S , T , and dictionary of D overlapping patch locations.

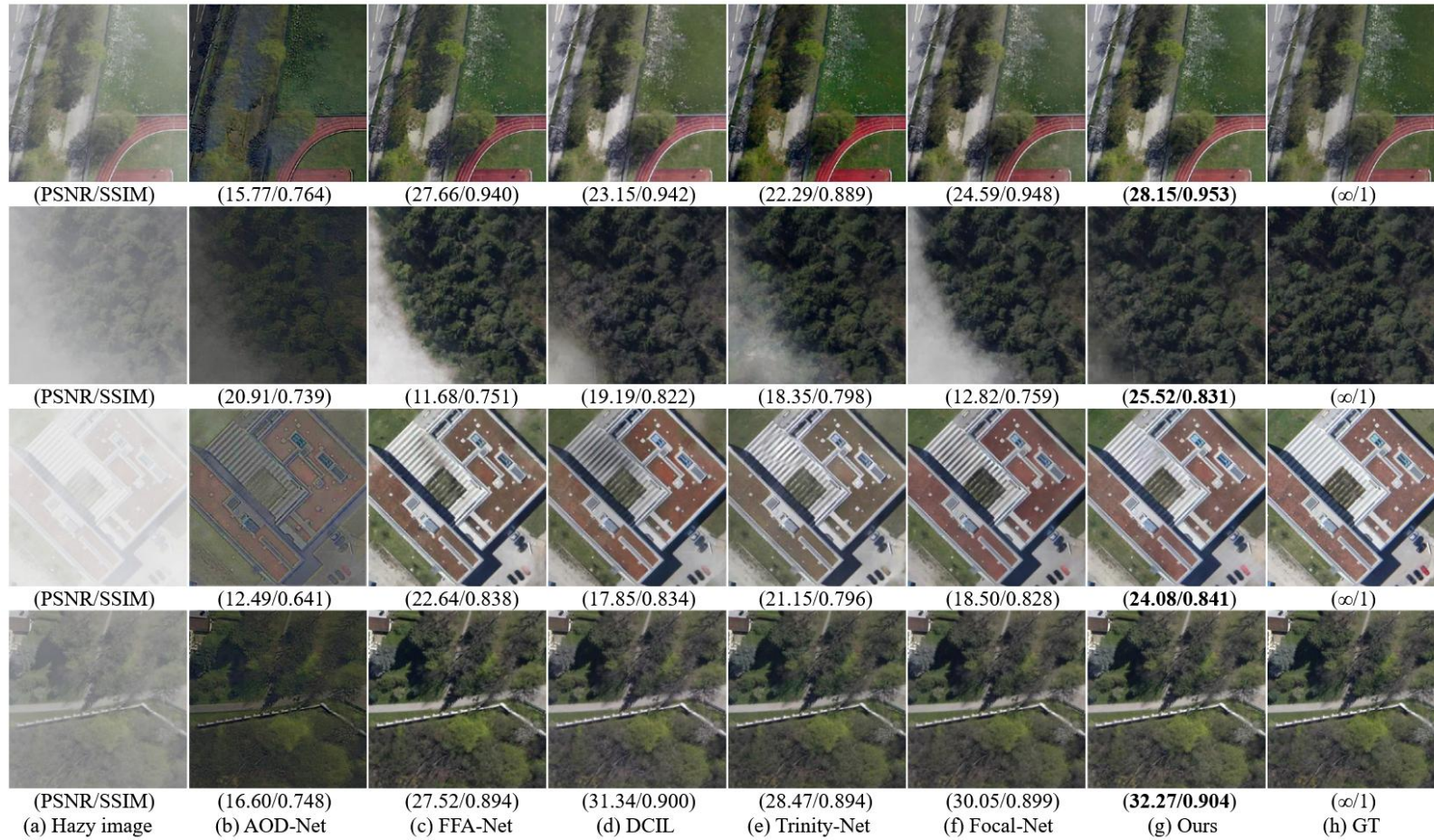
- 1: $y_{t_S} \sim \mathcal{N}(0, \mathbf{I})$
- 2: **for** $j = S : 1$ **do**
- 3: $t = (j - 1) \cdot T / (S - 1) + 1$
- 4: $t_{next} = (j - 2) \cdot T / (S - 1) + 1$ **if** $j > 1$ **else** 0
- 5: $\hat{\Omega}_t = \mathbf{0}$ and $\mathbf{M} = \mathbf{0}$
- 6: **for** $d = 1 : D$ **do**
- 7: $y_t^{(d)} = \text{Crop}(\mathbf{P}_d \circ y_t)$ and $\bar{x}^{(d)} = \text{Crop}(\mathbf{P}_d \circ \bar{x})$
- 8: $\hat{\Omega}_t = \hat{\Omega}_t + \mathbf{P}_d \cdot \epsilon_\theta(y_t^{(d)}, \bar{x}^{(d)}, t)$
- 9: $\mathbf{M} = \mathbf{M} + \mathbf{P}_d$
- 10: **end for**
- 11: $\hat{\Omega}_t = \hat{\Omega}_t \oslash \mathbf{M}$ // \oslash : element-wise division
- 12: $y_{next} = \sqrt{\bar{\alpha}_{t_{next}}} \left(\frac{y_t - \sqrt{1 - \bar{\alpha}_t} \cdot \hat{\Omega}_t}{\sqrt{\bar{\alpha}_t}} \right) + \sqrt{1 - \bar{\alpha}_{t_{next}}} \cdot \hat{\Omega}_t$
- 13: **end for**
- 14: **return** y_0

Fast Fourier Block



Method	Publication	LHID					DHID				
		PSNR \uparrow	SSIM \uparrow	CIEDE2000 \downarrow	LPIPS \downarrow	FID \downarrow	PSNR \uparrow	SSIM \uparrow	CIEDE2000 \downarrow	LPIPS \downarrow	FID \downarrow
DCP [8]	TPAMI'10	21.12	0.818	9.161	0.481	21.49	18.92	0.824	9.867	0.163	79.92
AOD-Net [14]	ICCV'17	22.24	0.842	7.122	0.475	32.61	15.37	0.718	14.272	0.269	151.16
GridDehazeNet [17]	ICCV'19	26.64	0.883	4.597	0.451	18.86	25.51	0.868	5.053	0.121	65.95
IDeRs [10]	INS'19	14.68	0.627	19.563	0.633	44.65	13.33	0.575	19.942	0.344	120.17
FFA-Net [54]	AAAI'20	27.79	0.887	4.424	0.451	16.27	25.05	0.880	5.590	0.144	73.27
PhysicsGAN [25]	TPAMI'20	22.01	0.835	8.198	0.512	38.72	19.85	0.824	10.415	0.187	94.61
PSD [18]	CVPR'21	23.33	0.855	6.998	0.549	37.25	23.30	0.853	6.911	0.163	82.66
FCTF-Net [20]	GRSL'21	25.85	0.876	5.423	0.459	21.21	17.21	0.739	12.794	0.221	128.49
DCIL [21]	TGRS'22	28.12	0.898	5.180	0.447	14.93	26.95	0.896	4.877	0.131	64.73
SGID-PFF [22]	TIP'22	24.12	0.852	7.091	0.488	30.13	25.69	0.867	6.147	0.158	80.74
Trinity-Net [34]	TGRS'23	24.78	0.867	6.737	0.460	17.76	25.86	0.878	5.479	0.139	75.46
RIDCP [61]	CVPR'23	26.75	0.843	4.553	0.128	19.07	26.15	0.874	5.329	0.136	64.36
C ² PNet [62]	CVPR'23	28.65	0.867	4.065	0.086	15.16	26.20	0.871	4.925	0.106	56.40
Focal-Net [19]	ICCV'23	29.39	0.899	4.012	0.445	14.32	25.73	0.887	5.313	0.131	73.04
PSMB-Net [63]	TGRS'23	28.89	0.900	5.864	0.454	16.13	27.07	0.887	4.965	0.113	53.83
AU-Net [64]	TGRS'24	28.44	0.893	4.045	0.451	16.96	26.42	0.891	4.489	0.138	69.28
Ours	-	29.65	0.905	3.875	0.436	12.85	27.91	0.900	3.945	0.102	49.52

Experiment



Experiment

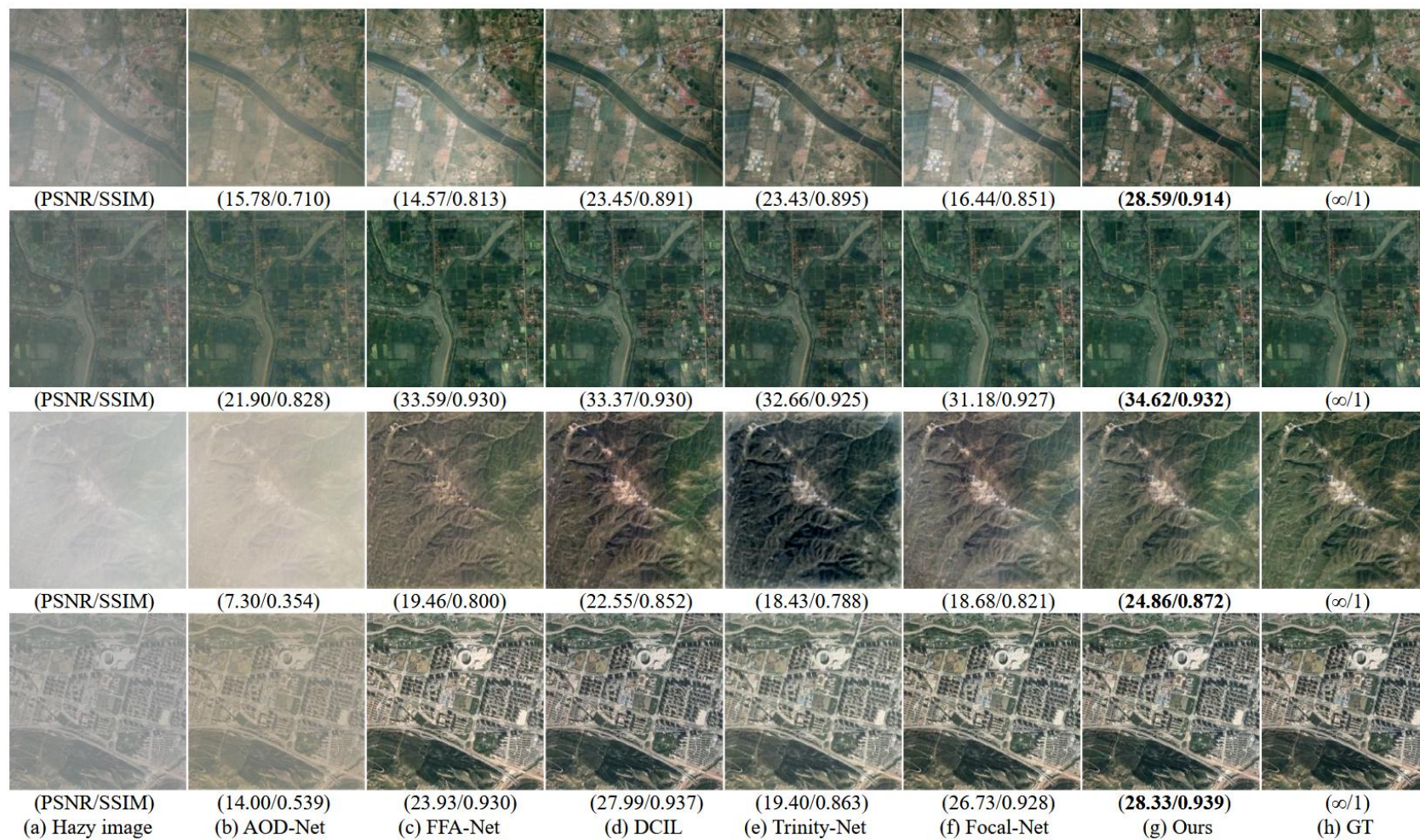


TABLE II

QUANTITATIVE COMPARISONS ON THE NIGHTTIME HAZY DATASET NHM

Method	Publication	PSNR \uparrow	SSIM \uparrow
NDIM [72]	ICIP'14	12.69	0.617
GS [73]	ICCV'15	11.85	0.615
MRP [74]	CVPR'17	13.11	0.655
FAST-MRP [74]	CVPR'17	13.31	0.649
OSFD [60]	MM'20	13.28	0.667
VD [75]	CVPRW'22	13.77	0.687
GHLP [76]	TIP'22	13.15	0.674
GAPSF [77]	MM'23	13.48	0.665
NightHazeFormer [36]	MM'23	18.54	0.784
Ours	-	15.86	0.786

TABLE III

AVERAGE PSNR, SSIM AND CIEDE2000 OF VARIOUS DIFFERENT APPROACHES ON THE REAL-WORLD ERICE DATASET

Method	Publication	PSNR \uparrow	SSIM \uparrow	CIEDE2000 \downarrow
DCP [8]	TPAMI'10	18.13	0.816	11.482
AOD-Net [14]	ICCV'17	20.18	0.807	9.438
GridDehazeNet [17]	ICCV'19	32.73	0.935	2.719
IDeRs [10]	INS'19	13.29	0.513	20.701
FFA-Net [54]	AAAI'20	30.81	0.932	3.475
PSD [18]	CVPR'21	26.58	0.918	5.218
FCTF-Net [20]	GRSL'21	33.13	0.933	3.626
DCIL [21]	TGRS'22	35.90	0.942	2.068
Trinity-Net [34]	TGRS'23	30.26	0.942	4.026
Focal-Net [19]	ICCV'23	32.67	0.937	2.691
Ours	-	36.56	0.958	2.642

Thanks
