Interpretable Unsupervised Joint Denoising and Enhancement for Real-World low-light Scenarios

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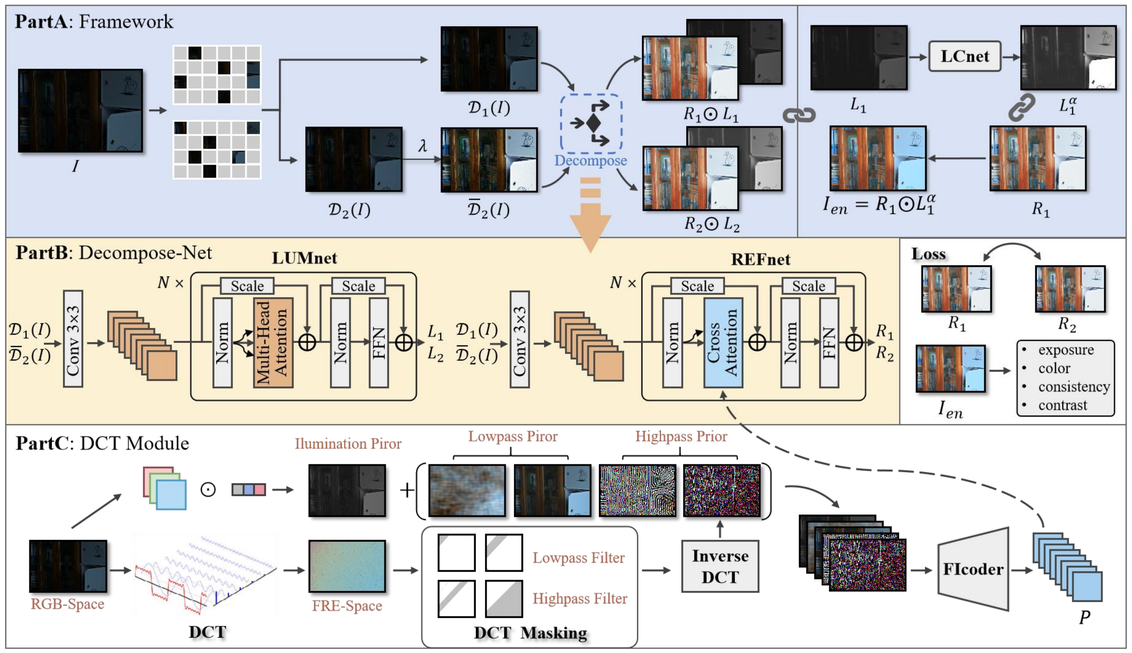
Pipeline



The resulting sub-images can thus be mathematically formulated as:

$$\mathcal{D}_1(I) = (R_1 + N_1) \circ L_1, \mathcal{D}_2(I) = (R_2 + N_2) \circ L_2$$

we apply gamma correction to $\mathcal{D}_2(I)$ and get $\overline{\mathcal{D}}_2(I)$ and given that N_2 is relatively small compared to the pixel values, we further perform a Taylor series expansion on it:

$$\overline{\mathcal{D}}_2(I) = \mathcal{D}_2(I)^\lambda = (R_2 + N_2)^\lambda \circ L_2^\lambda \approx (R_2^\lambda + \lambda R_2^{\lambda-1} N_2) \circ L_2^\lambda = (R_2 + \lambda N_2) \circ R_2^{\lambda-1} \circ L_2^\lambda$$

leading to the final expressions for the two sub-images:

$$\mathcal{D}_1(I) = (R_1 + N_1) \circ L_1, \overline{\mathcal{D}}_2(I) = (R_2 + \lambda N_2) \circ \overline{L}_2$$

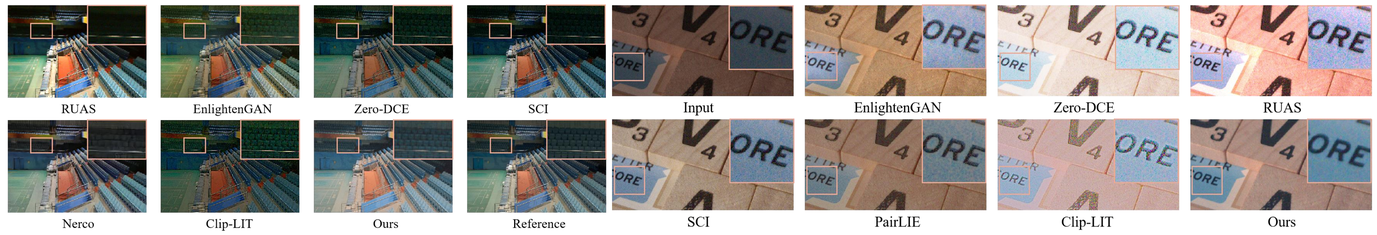
Frequency-illumination Prior

$$M_{low\_1}(u,v) = 1 \ if \ u+v \le t \ else \ 0, M_{low\_2}(u,v) = 1 \ if \ u+v \le 3t \ else \ 0,$$
$$M_{high\_1}(u,v) = 1 \ if \ 2t < u+v \le 4t \ else \ 0, M_{high\_2}(u,v) = 1 \ if \ u+v \ge 5t \ else \ 0.$$

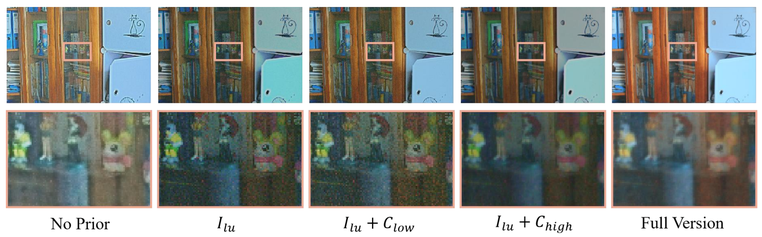
Benchmarking Results

Method	Reference	LOLv1 PSNR↑	LOLv1 SSIM↑	LOLv1 LPIPS↓	LOLv2-Real PSNR↑	LOLv2-Real SSIM↑	LOLv2-Real LPIPS↓
Supervised							
URetinexNet	Wu et al. (2022)	19.84	0.824	0.237	21.09	0.858	0.208
SNR-aware	Xu et al. (2022)	24.61	0.842	0.233	21.48	0.849	0.237
LLFormer	Wang et al. (2023)	23.65	0.818	0.169	27.75	0.861	0.142
Retinexformer	Cai et al. (2023)	23.93	0.831	——	21.23	0.838	——
Retinexmamba	Bai et al. (2024)	24.03	0.831	——	22.45	0.844	——
Unpaired							
EnlightenGAN	Jiang et al. (2021)	17.48	0.651	0.322	18.64	0.675	0.308
PairLIE	Fu et al. (2023)	19.51	0.736	**0.247**	**19.70**	**0.774**	**0.235**
Nerco	Yang et al. (2023)	19.70	**0.742**	**0.234**	19.66	0.717	0.270
No-Reference							
ZERO-DCE	Guo et al. (2020)	14.86	0.559	0.335	18.06	0.573	0.312
RUAS	Liu et al. (2021)	16.40	0.500	0.270	15.33	0.488	0.310
Sci-easy	Ma et al. (2022)	9.58	0.369	0.410	11.98	0.399	0.354
Sci-medium		14.78	0.522	0.339	17.30	0.534	0.308
Sci-hard		13.81	0.526	0.358	17.25	0.546	0.317
Clip-LIT	Liang et al. (2023)	17.21	0.589	0.335	17.06	0.589	0.352
Enlighten-Your-Voice	Zhang et al. (2023)	**19.73**	0.715	——	19.34	0.686	——
Ours		**19.80**	**0.750**	0.253	**20.22**	**0.793**	**0.266**

Method	Parameters	SICE PSNR↑	SICE SSIM↑	SICE LPIPS↓	SIDD BRSIQUE↓	SIDD CLIPIQA↓
Supervised						
URetinexNet	1.04M	22.12	0.844	0.462	——	——
SNR-aware	50.95M	15.02	0.584	0.527	25.679	0.294
LLFormer	72.29M	17.88	0.821	0.503	3.548	0.339
Retinexformer	1.61M	——	——	——	9.229	0.343
Retinexmamba	4.59M	——	——	——	11.826	0.386
Unpaired						
EnlightenGAN	8.44M	18.73	0.822	**0.216**	13.786	**0.337**
PairLIE	0.34M	**21.32**	**0.840**	**0.216**	**3.168**	0.383
Nerco	22.76M	18.72	0.805	0.474	——	——
No-Reference						
ZERO-DCE	0.08M	18.69	0.810	0.279	24.291	0.503
RUAS	0.01M	13.18	0.734	0.363	31.613	0.361
Sci-easy	0.01M	11.71	0.590	0.502	25.344	0.399
Sci-medium		15.95	0.787	0.335	21.636	0.456
Sci-hard		17.59	0.782	0.486	35.533	0.508
Clip-LIT	0.27M	13.70	0.725	0.480	31.093	0.434
Ours	0.36M	**22.55**	**0.841**	**0.234**	**2.555**	**0.292**



Ablation Study



Illumination	Lowpass	Highpass	LOLv1 PSNR↑	LOLv1 SSIM↑	LOLv1 LPIPS↓
×	×	×	18.88	0.741	0.273
✓	×	×	19.54	**0.753**	**0.253**
✓	×	✓	**19.69**	0.744	**0.259**
✓	✓	×	19.57	0.745	0.262
✓	✓	✓	**19.80**	**0.750**	**0.253**