Reti-Diff: Illumination Degradation Image Restoration with Retinex-based Latent Diffusion Model

Chunming He[1,*], Chengyu Fang[2,*,†], Yulun Zhang[3,†], Longxiang Tang[2], Jinfa Huang[4], Kai Li[5], Zhenhua Guo[6], Xiu Li[2], Sina Farsiu[1,†]

[1] Duke University, [2] Tsinghua University, [3] Shanghai Jiao Tong University, [4] Peking University, [6] Meta, [7] Tianyi Traffic Technology

Introduction

Challenges:

(1) In the illumination degradation image restoration (IDIR) task, existing diffusion model (DM)-based methods incur **high computational costs**, as predicting the image-level distribution requires a large number of inference steps.

(2) The enhanced results of existing DM-based approaches may exhibit **pixel misalignment** with the original clean image in terms of restored details and local consistency.

Contribution:

1. We propose a novel DM-based framework, Reti-Diff, for the IDIR task. To the best of our knowledge, this is the **first** practice of the latent diffusion model to tackle IDIR.

2. We propose to let RLDM learn Retinex knowledge and generate high-quality reflectance and illumination priors from the low-quality input, which serve as critical guidance in detail enhancement and illumination correction and **can be integrated with various methods**.

3. We propose RGformer, which integrates extracted priors to decompose features into reflectance and illumination components, ensuring robustness and generalization.

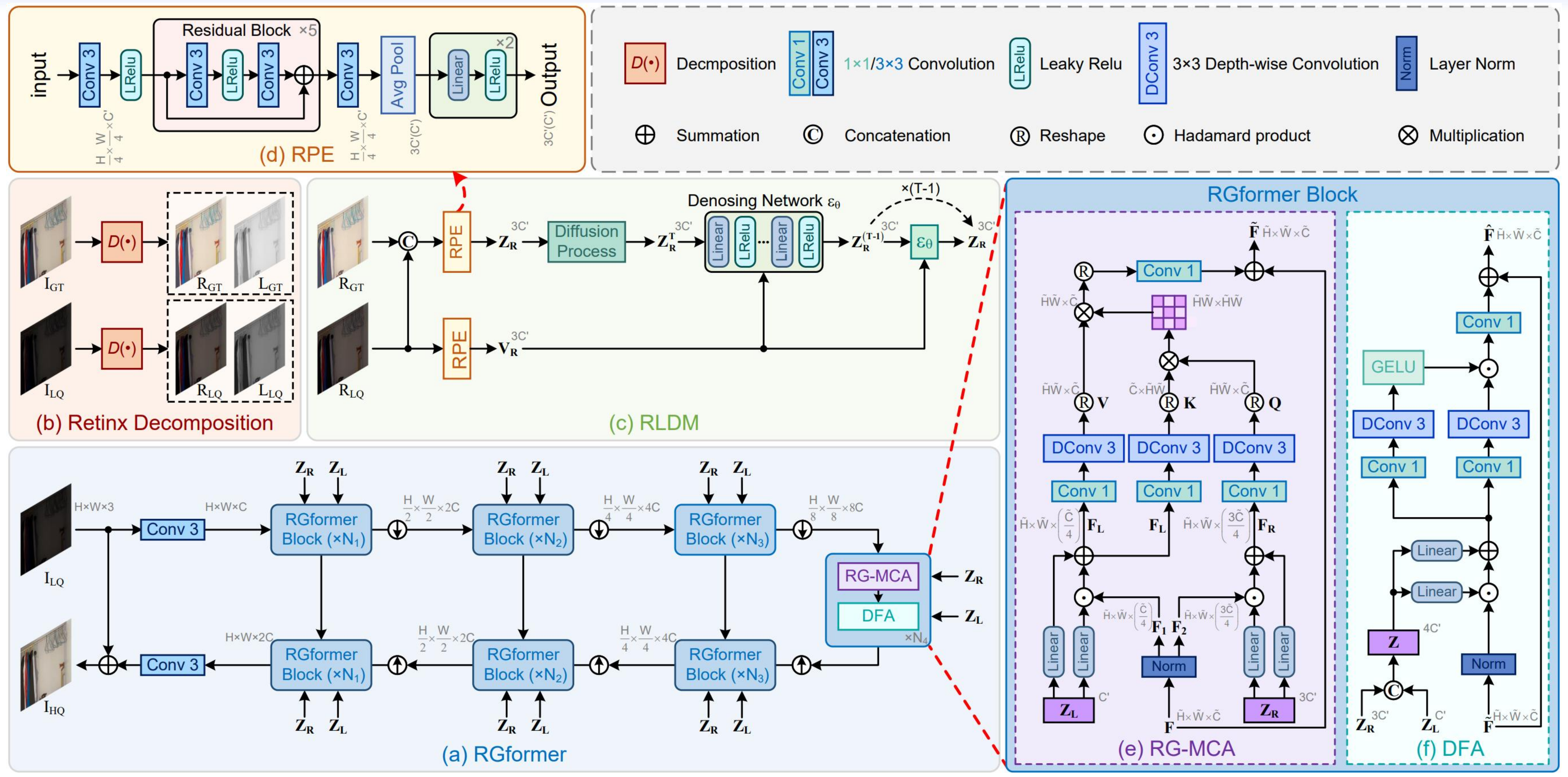
4. Extensive experiments on four IDIR tasks verify our superiority, efficiency, and generalizability to existing methods in terms of image quality and favorability in downstream applications, including low-light object detection and image segmentation.

Information

Code: https://github.com/ChunmingHe/Reti-Diff

Wechat: 15112561951 **Email:** chunming.he@duke.edu

Network architecture



Framework of our Reti-Diff. In Phase I, we pretrain Reti-Diff with RGformer and RPE to ensure the robust learning of RLDM. In Phase II, we optimize RLDM to generate high-quality Retinex priors to guide RGformer in detail enhancement and illumination correction.

Experiment

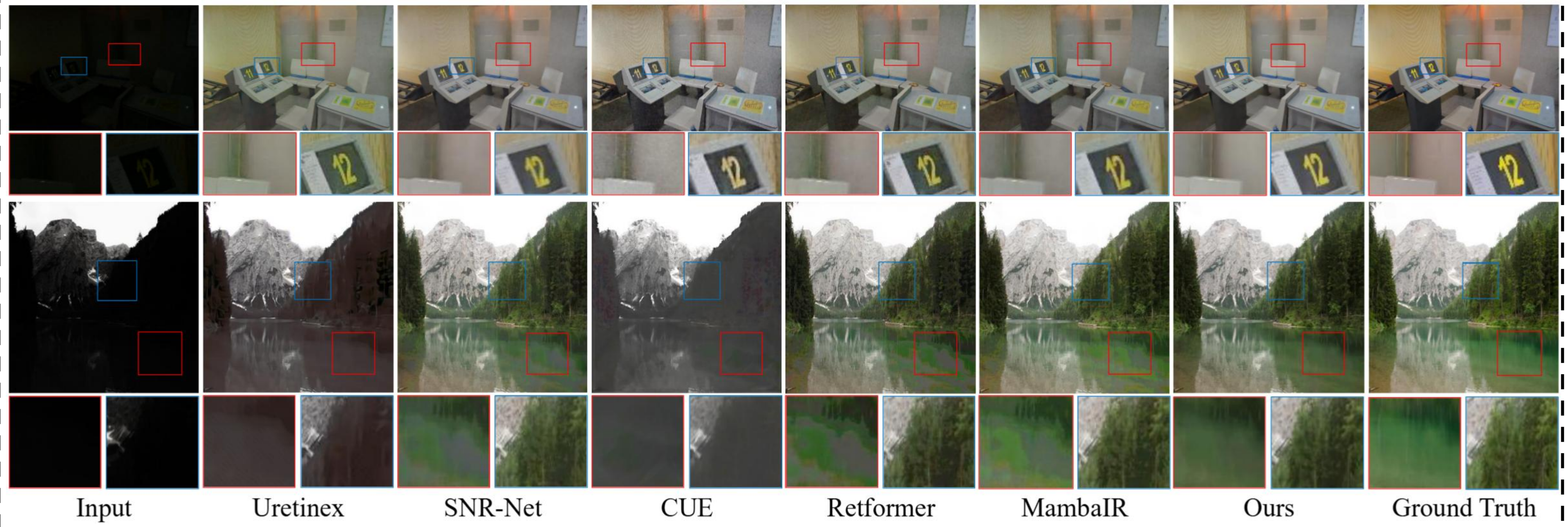
Methods	Sources	LOL-v1 PSNR ↑	SSIM ↑	FID ↓	BIQE ↓	LOL-v2-real PSNR ↑	SSIM ↑	FID ↓	BIQE ↓	LOL-v2-synthetic PSNR ↑	SSIM ↑	FID ↓	BIQE ↓	SID PSNR ↑	SSIM ↑	FID ↓	BIQE ↓
MIRNet (Zamir et al., 2020)	ECCV20	24.14	0.835	71.16	47.75	20.02	0.820	82.25	41.18	21.94	0.876	40.18	36.29	20.84	0.605	81.37	40.63
EnGAN (Jiang et al., 2021)	TIP21	17.48	0.656	153.98	35.82	18.23	0.617	173.28	51.06	16.57	0.734	93.66	45.59	17.23	0.543	77.52	33.47
RUAS (Liu et al., 2021)	CVPR21	18.23	0.723	127.60	45.17	18.27	0.723	151.62	34.73	16.55	0.652	91.60	46.38	18.44	0.581	72.18	45.02
IPT (Chen et al., 2021)	CVPR21	16.27	0.504	158.83	29.35	19.80	0.813	97.24	31.17	18.30	0.811	76.79	42.15	20.53	0.618	70.58	36.71
URetinex (Wu et al., 2022)	CVPR22	21.33	0.835	85.59	30.37	20.44	0.806	76.74	28.85	24.73	0.897	33.25	33.46	22.09	0.633	71.58	38.44
UFormer (Wang et al., 2022)	CVPR22	16.36	0.771	166.69	41.06	18.82	0.771	164.41	40.36	19.66	0.871	58.69	39.75	18.54	0.577	100.14	42.13
Restormer (Zamir et al., 2022)	CVPR22	22.43	0.823	78.75	33.18	19.94	0.827	114.35	37.27	21.41	0.830	46.89	35.06	22.27	0.649	75.47	32.49
SNR-Net (Xu et al., 2022)	CVPR22	24.61	0.842	66.47	28.73	21.48	0.849	68.56	28.83	24.14	0.928	30.52	33.47	22.87	0.625	74.78	30.08
SMG (Xu et al., 2023)	CVPR23	24.82	0.838	69.47	30.15	22.62	0.857	71.76	30.32	25.62	0.905	23.36	29.35	23.18	0.644	77.58	31.50
PyDiff (Zhou et al., 2023a)	IJCAI23	21.15	0.857	49.47	21.13	—	—	—	—	—	—	—	—	—	—	—	—
Retformer (Cai et al., 2023)	ICCV23	25.16	0.845	72.38	26.68	22.80	0.840	79.58	34.39	25.67	0.930	22.78	30.26	24.44	0.680	82.64	35.04
Diff-Retinex (Yi et al., 2023)	ICCV23	21.98	0.852	51.33	19.62	20.17	0.826	46.67	24.18	24.30	0.921	28.74	26.35	23.62	0.665	58.93	31.17
MRQ (Liu et al., 2023)	ICCV23	25.24	0.855	53.32	22.73	22.37	0.854	68.89	33.61	25.54	0.940	20.86	25.09	24.62	0.683	61.09	27.81
IAGC (Wang et al., 2023)	ICCV23	24.53	0.842	59.73	25.50	22.20	0.863	70.34	31.70	25.58	0.941	21.38	30.32	24.80	0.688	63.72	29.53
DiffIR (Xia et al., 2023)	ICCV23	23.15	0.828	70.13	26.38	21.15	0.816	72.33	29.15	24.76	0.921	28.87	27.74	23.17	0.640	78.80	30.56
CUE (Zheng et al., 2023)	ICCV23	21.86	0.841	69.83	27.15	21.19	0.829	67.05	28.83	24.41	0.917	31.33	33.83	23.25	0.652	77.38	28.85
GSAD (Jinhui et al., 2023)	NIPS23	23.23	0.852	51.64	19.96	20.19	0.847	46.77	28.85	24.22	0.927	19.24	25.76	—	—	—	—
AST (Zhou et al., 2024)	CVPR24	21.09	0.858	87.67	21.23	21.68	0.856	91.81	25.17	22.25	0.927	37.19	28.78	—	—	—	—
MambaIR (Guo et al., 2024)	ECCV24	22.23	0.863	63.39	20.17	21.15	0.857	56.09	24.46	25.75	0.958	19.75	20.37	21.14	0.656	154.76	32.72
Reti-Diff	Ours	**25.35**	**0.866**	**49.14**	**17.75**	**22.97**	**0.858**	**43.18**	**23.66**	**27.53**	**0.951**	**13.26**	**15.77**	**25.53**	**0.692**	**51.66**	**25.58**

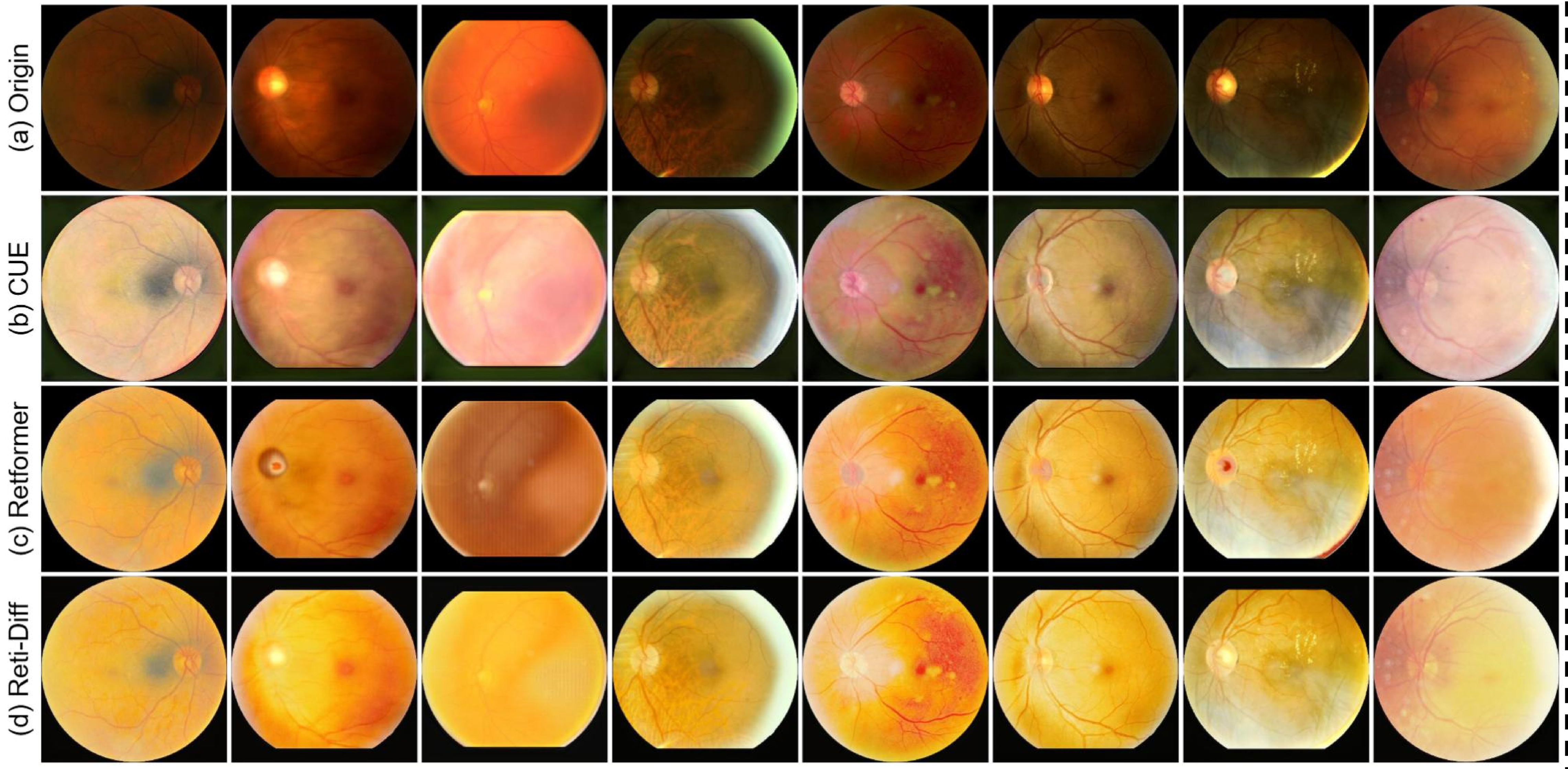
Results on the low-light image enhancement task.

Methods	Sources	UIEB PSNR ↑	SSIM ↑	UCIQE ↑	UIQM ↑	LSUI PSNR ↑	SSIM ↑	UCIQE ↑	UIQM ↑
FUGAN (Islam et al., 2020)	IRAL20	17.41	0.842	0.527	2.614	22.16	0.837	0.576	2.667
EnGAN (Jiang et al., 2021)	TIP21	17.73	0.833	0.529	2.465	19.30	0.851	0.587	2.817
Ucolor (Li et al., 2021)	TIP21	20.78	0.868	0.537	3.049	22.91	0.886	0.594	2.735
S-uwnet (Naik et al., 2021)	AAAI21	18.28	0.855	0.544	2.942	20.89	0.875	0.582	2.746
PUIE (Fu et al., 2022)	ECCV22	21.38	0.882	0.566	3.021	23.70	0.902	0.605	2.974
U-shape (Peng et al., 2023)	TIP23	22.91	0.905	0.592	2.896	24.16	0.917	0.603	3.022
PUGAN (Cong et al., 2023)	TIP23	23.05	0.897	0.608	2.902	25.06	0.916	0.629	3.106
ADP (Zhou et al., 2023b)	IJCV23	22.90	0.892	0.621	3.005	24.28	0.913	0.626	3.075
NU2Net (Guo et al., 2023)	AAAI23	22.38	0.903	0.587	2.936	25.07	0.908	0.615	3.112
AST (Zhou et al., 2024)	CVPR24	22.19	0.908	0.602	2.981	27.46	0.916	0.632	3.107
MambaIR (Guo et al., 2024)	ECCV24	22.60	0.939	0.617	2.991	27.68	0.916	0.630	3.118
Reti-Diff	Ours	**24.12**	**0.910**	**0.631**	**3.088**	**28.10**	**0.929**	**0.646**	**3.208**

Methods	Sources	BAID PSNR ↑	SSIM ↑	LPIPS ↓	FID ↓
EnGAN (Jiang et al., 2021)	TIP21	17.96	0.819	0.182	43.55
RUAS (Liu et al., 2021)	CVPR21	18.92	0.813	0.262	40.07
URetinex (Wu et al., 2022)	CVPR22	19.08	0.845	0.206	42.26
SNR-Net (Xu et al., 2022)	CVPR22	20.86	0.860	0.213	39.73
Restormer (Zamir et al., 2022)	CVPR22	21.07	0.832	0.192	41.17
Retformer (Cai et al., 2023)	ICCV23	22.03	0.862	0.173	45.27
CLIP-LIT (Liang et al., 2023)	ICCV23	21.13	0.853	0.159	37.30
Diff-Retinex (Yi et al., 2023)	ICCV23	22.07	0.861	0.160	38.07
DiffIR (Xia et al., 2023)	ICCV23	21.10	0.835	0.175	40.35
AST (Zhou et al., 2024)	CVPR24	22.61	0.851	0.156	32.47
MambaIR (Guo et al., 2024)	ECCV24	23.07	0.874	0.153	29.13
Reti-Diff	Ours	**23.19**	**0.876**	**0.147**	**27.47**

Results on underwater image enhancement and backlit image enhancement tasks.





Visualization on low-light images and generalization on fundus images.