Brighten-and-Colorize: A Decoupled Network for Customized Low-Light Image Enhancement

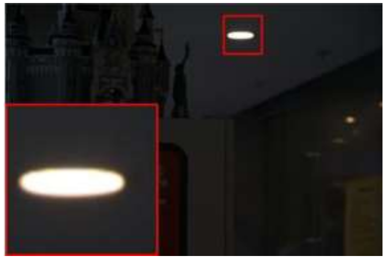
ACM MM 2023

Introduction

Low-light Image Enhancement

- Lightness
- Color / Chrominance   RGB channels constraint, Color consistency loss, …

Recent advances mainly focus on the refinement of the lightness, while **ignoring the role of chrominance**.
It easily leads to **chromatic aberration or artifacts**.



MIRNet-v2 (TPAMI 2022)

GT

Introduction

Image Colorization → Low-light Image Color Recover

Key challenges:

- How to ensure boundaries of the generated chrominance?
- How to solve the problem that one object can be filled by multiple colors ?

semantic information

color strokes, reference image

Although the chrominance of low-light image is unsaturated, **it contains both boundary information and some color hints**.

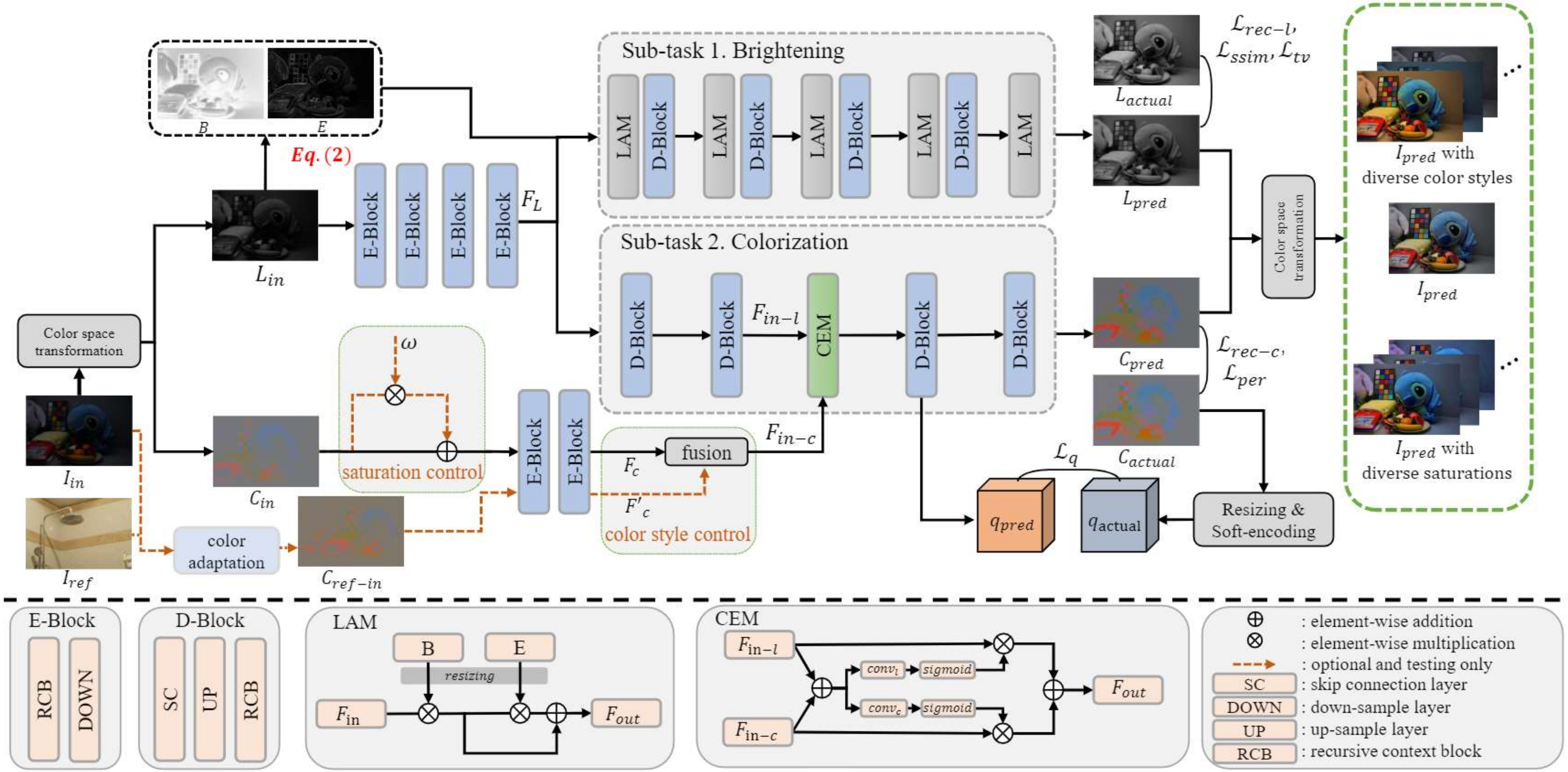
↓

low-light chrominance as a guidance to recover proper colors. → customized enhancement

- customized saturation
- customized color style

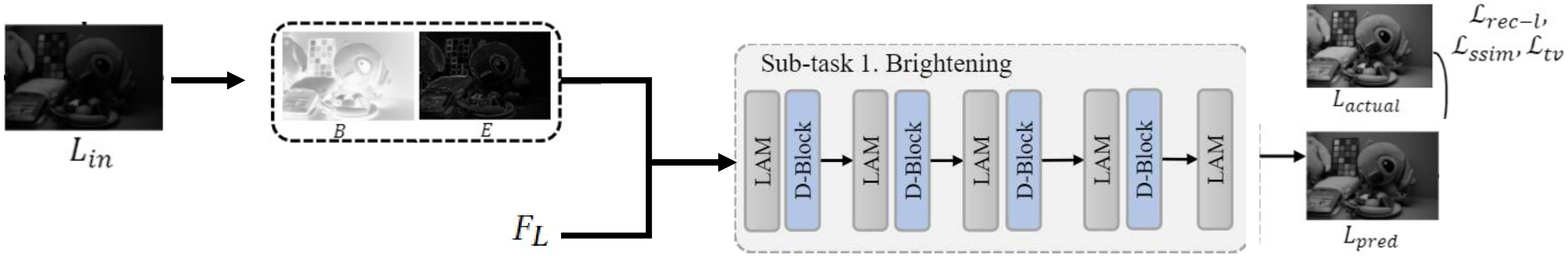
LLIE is decoupled into the **brightening** and **colorization** sub-tasks.

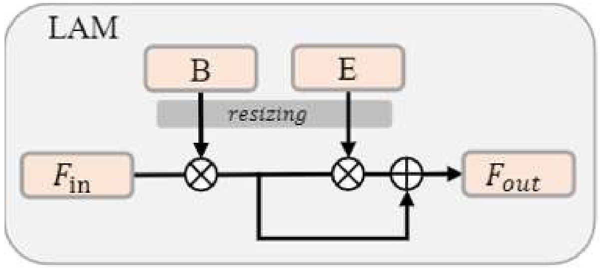
Framework



Sub-task 1. Brightening
Sub-task 2. Colorization
LAM
D-Block
E-Block
CEM
Eq. (2)
F_L
L_{in}
I_{in}
I_{ref}
C_{in}
C_{ref-in}
Color space transformation
color adaptation
saturation control
color style control
fusion
ω
F_c
F'_c
F_{in-l}
F_{in-c}
L_{actual}
L_{pred}
C_{pred}
C_{actual}
$\mathcal{L}_{rec-l}$, $\mathcal{L}_{ssim}$, $\mathcal{L}_{tv}$
$\mathcal{L}_{rec-c}$, $\mathcal{L}_{per}$
$\mathcal{L}_q$
q_{pred}
q_{actual}
Resizing & Soft-encoding
I_{pred} with diverse color styles
I_{pred}
I_{pred} with diverse saturations
E-Block
RCB
DOWN
D-Block
SC
UP
RCB
LAM
B
E
resizing
F_{in}
F_{out}
CEM
F_{in-l}
F_{in-c}
$conv_l$
$conv_c$
sigmoid
F_{out}
⊕ : element-wise addition
⊗ : element-wise multiplication
: optional and testing only
SC : skip connection layer
DOWN : down-sample layer
UP : up-sample layer
RCB : recursive context block

Brightening





Lightness Adjustment Module

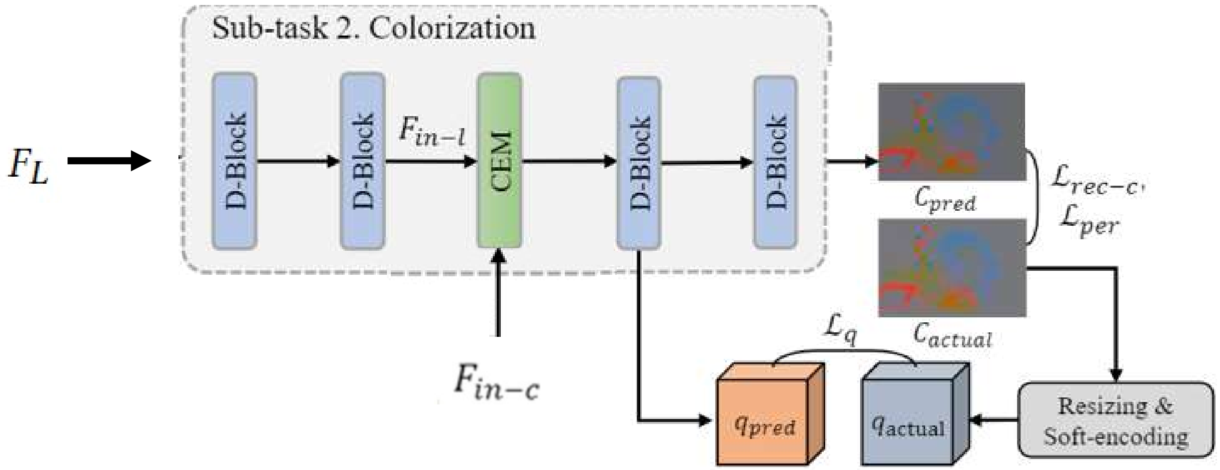
$$F_L = Encoder(L_{in})$$

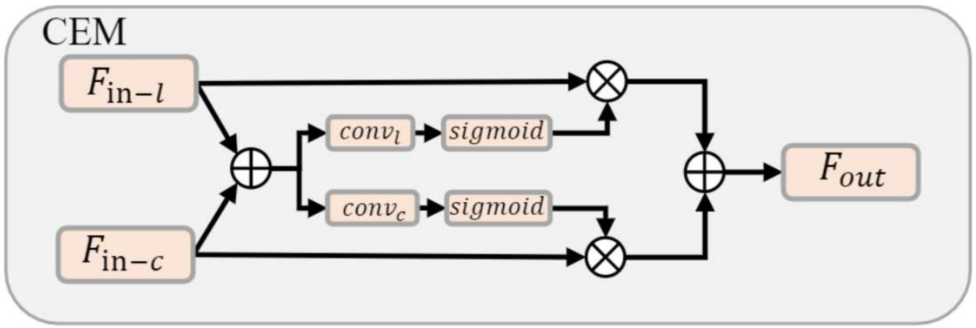
$$B = 1 - L_{in}, E = edge(L_{in})$$

$$F_{out} = F_{in} \times \psi(B) \times (1 + \psi(E))$$

$$\mathcal{L}_{rec-l} = \sqrt{\left\|L_{actual} - L_{pred}\right\|_2 + \epsilon^2}$$

Colorization





Color Embedding Module

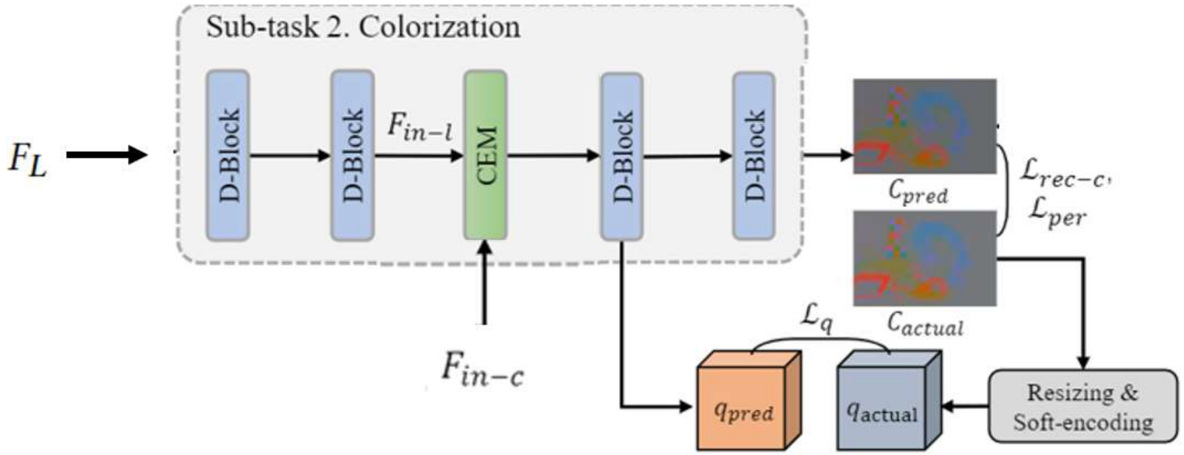
$$\hat{F_{in}} = F_{in-l} + F_{in-c}$$

$$A_l = sigmoid(conv_l(\hat{F_{in}})) \quad A_c = sigmoid(conv_c(\hat{F_{in}}))$$

$$F_{out} = F_{in-l} \times A_l + F_{in-c} \times A_c$$

$$\mathcal{L}_{rec-c} = \left\|C_{actual} - C_{pred}\right\|_1$$

Colorization



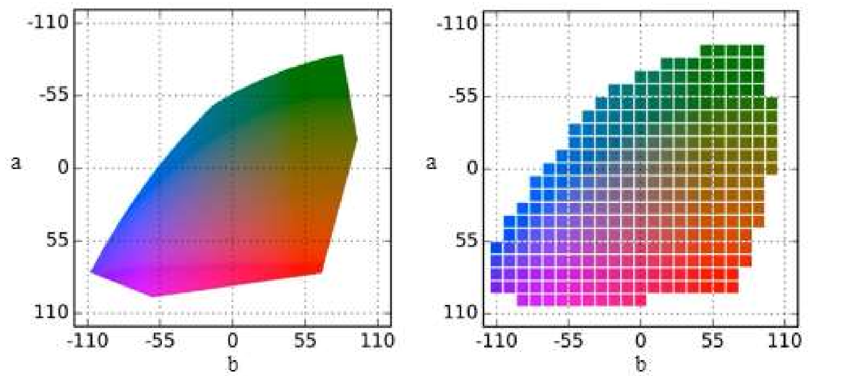


Figure 3: The quantization operation [48] in CIELAB color space. The continuous colors (left) are quantized to 313 discrete colors (right) with a grid size of 10.

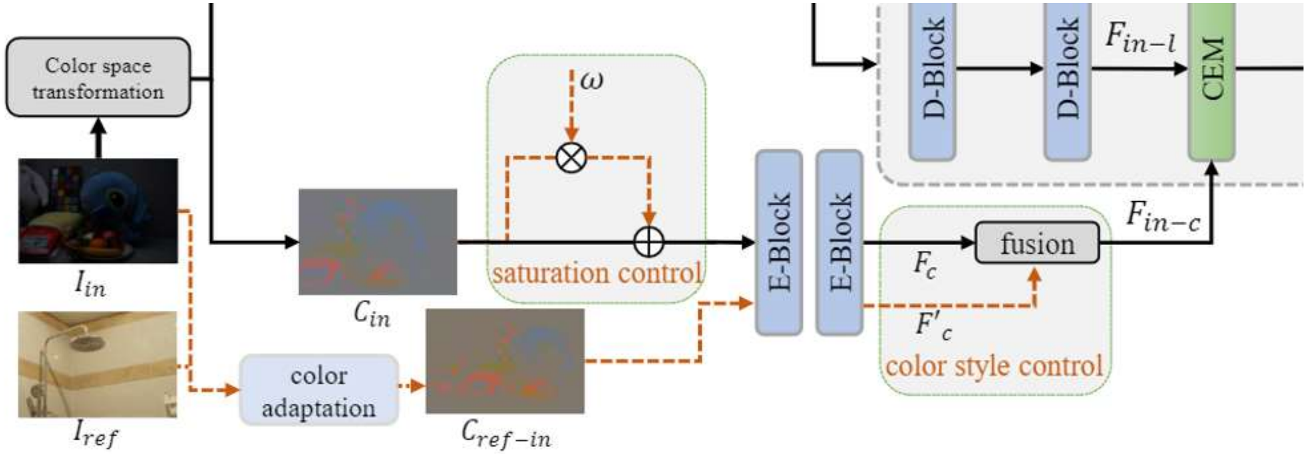
Color Classification Loss

$$\mathcal{L}_q = \mathcal{H}(q_{actual}, q_{pred})$$

$$= -\sum_{h,w}\sum_{p} q_{actua\ h,w,p} \log(q_{pred_{h,w,p}})$$

$$q_{pred} \in \mathbb{R}^{h\times w\times 313}$$

Customized Enhancement



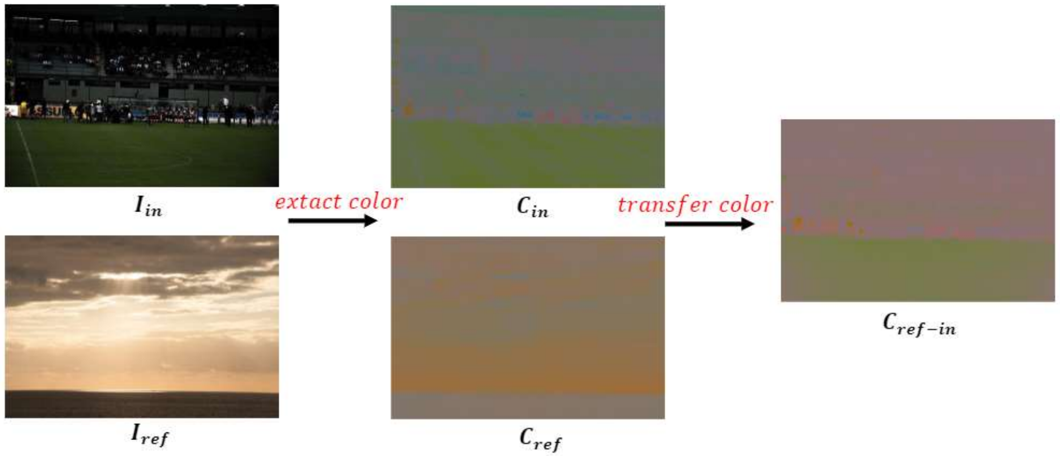
Saturation Control

$$C_{in} \times (1 + \omega)$$

Color Style Control.

$$(1 - \gamma) \times F_c + \gamma \times F_c'$$

Color Adaptation



$$L_{in}, a_{in}, b_{in} = RGB2Lab(I_{in})$$
$$L_{ref}, a_{ref}, b_{ref} = RGB2Lab(I_{ref})$$

$$a_{in} = a_{in} - mean(a_{in}), b_{in} = b_{in} - mean(b_{in})$$
$$a_{in} = a_{in} \times (std(a_{in})/std(a_{ref}))$$
$$b_{in} = b_{in} \times (std(b_{in})/std(b_{ref}))$$

$$C_{ref-in} = cat(a_{in}, b_{in})$$

Experiments

Table 1: Quantitative comparison on the LOL-real [43] and FiveK [1]. The best results are boldfaced and the second-best ones are underlined.

Methods	LOL-real [43]					FiveK [1]					Size (M)
	PSNR ↑	SSIM ↑	ΔE_ab↓	LPIPS ↓	CSE (ratio) ↓	PSNR ↑	SSIM ↑	ΔE_ab ↓	LPIPS ↓	CSE (ratio) ↓	
DRD[39]	16.08	0.6555	22.35	0.2364	2.53	21.68	0.8604	10.52	0.0574	2.18	**0.86**
Kind[52]	20.01	0.8412	12.53	0.0813	1.30	20.71	0.8835	10.75	0.0480	1.38	8.02
Kind++[51]	20.59	0.8294	12.51	0.0875	1.18	19.71	0.8640	14.05	0.0574	2.12	8.27
MIRNet[46]	<u>22.11</u>	0.7942	<u>10.11</u>	0.1448	1.35	24.41	0.9097	7.90	0.0344	<u>1.33</u>	31.79
EnGAN[8]	18.64	0.6767	17.73	0.1512	6.18	15.38	0.7752	18.89	0.0984	2.97	8.64
DeepUPE[37]	18.68	0.5791	17.54	0.1868	9.48	24.24	0.8957	8.16	0.0440	2.15	<u>0.99</u>
DeepLPF[25]	20.03	0.7819	12.58	0.1460	3.23	24.74	0.9170	7.50	0.0570	1.44	1.72
UEGAN[26]	20.30	0.7417	14.69	0.1464	12.97	23.00	0.8717	9.96	0.0503	3.84	4.16
SGM[43]	20.06	0.8158	11.36	0.0727	1.33	22.57	0.8823	9.36	0.0557	4.23	2.31
MIRNet-v2[45]	21.83	0.8455	11.47	<u>0.0666</u>	1.49	25.04	0.9188	8.05	0.0357	1.54	5.86
SNR-Aware[41]	21.48	<u>0.8478</u>	10.58	0.0740	<u>1.14</u>	<u>25.41</u>	<u>0.9234</u>	<u>7.24</u>	<u>0.0293</u>	1.49	39.12
Ours	**23.27**	**0.8637**	**8.97**	**0.0566**	**1.00**	**25.74**	**0.9285**	**6.77**	**0.0291**	**1.00**	6.84

$\triangle E\_ab$: $L2\_distance$ in CIELab color space

CSE: Color Sensitive Error

Experiments

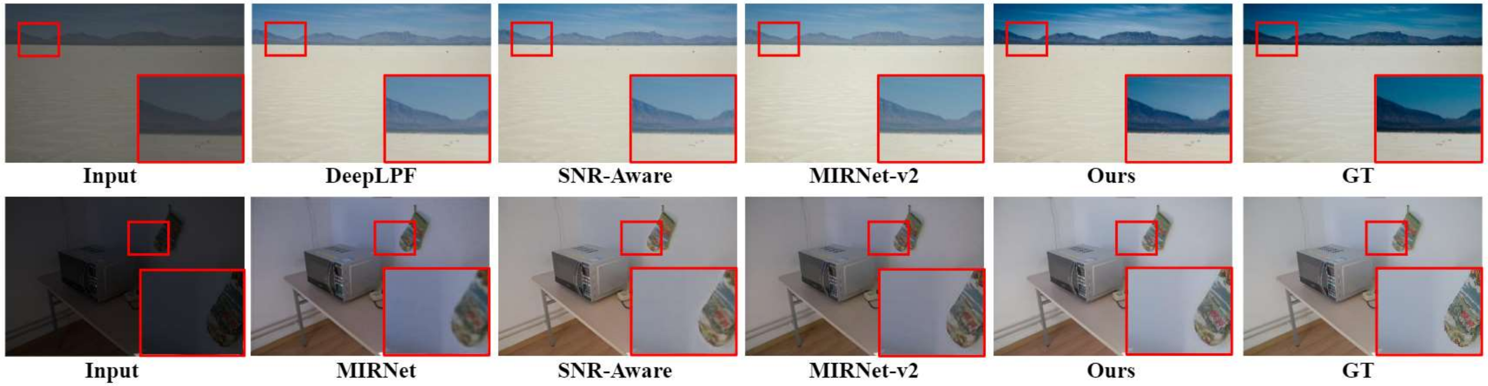
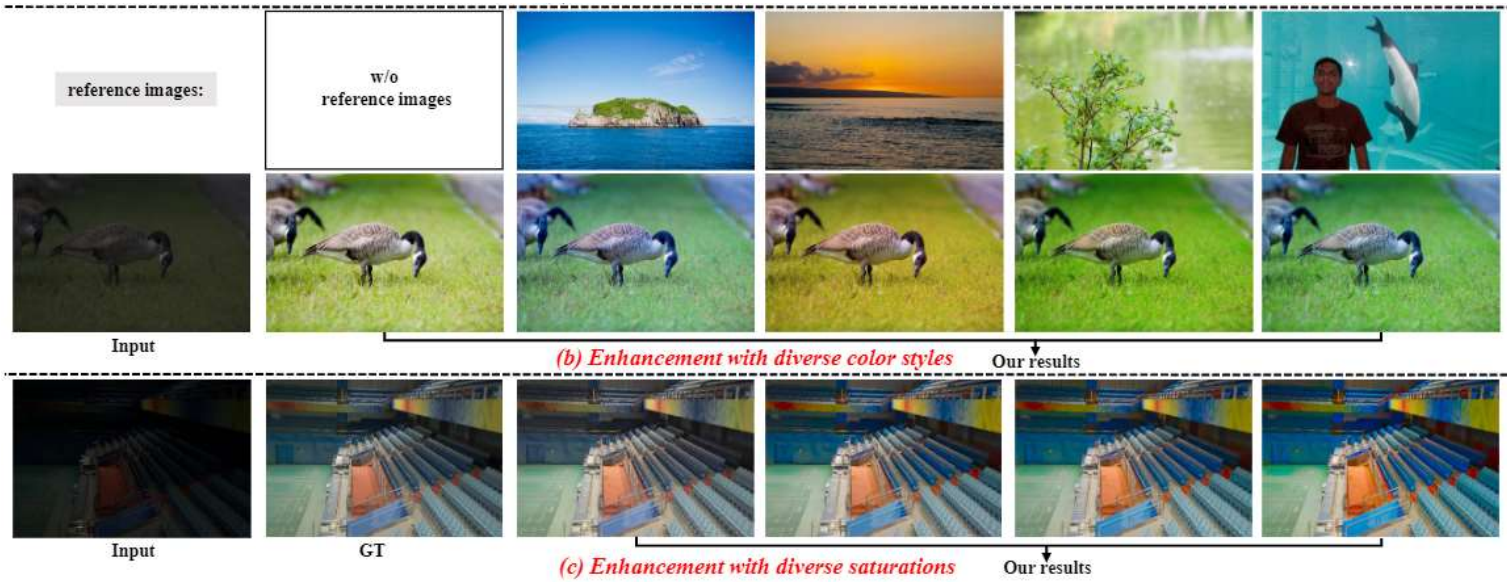


Figure 8: The qualitative comparison on FiveK [1] (the first row) and LOL-real [43] (the second row). It can be seen that the proposed method reaches the best visual results.



Experiments

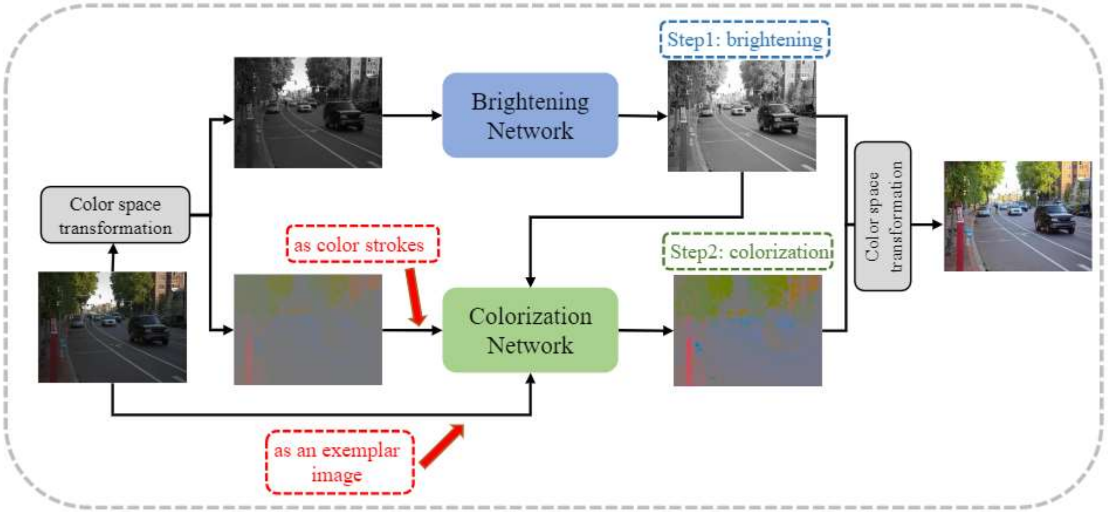


Table 2: Quantitative comparison with two-step "brighten-and-colorize" methods on LOL-real [43] dataset. The best results are boldfaced and the second-best ones are underlined. Note that "*" represents this method is retrained.

Brightener	Colorizer	PSNR ↑	SSIM ↑	CSE(ratio) ↓
SNR-Aware [41]	Zhang *et al.** [50]	20.90	<u>0.8304</u>	1.34
	Zhang *et al.* [50]	11.81	0.5411	70.44
	Yin *et al.* [44]	19.69	0.7881	7.40
MIRNet-v2 [45]	Zhang *et al.** [50]	<u>21.91</u>	0.8242	<u>1.09</u>
	Zhang *et al.* [50]	12.01	0.5313	77.60
	Yin *et al.* [44]	20.44	0.7810	7.30
Ours		**23.27**	**0.8637**	**1.00**

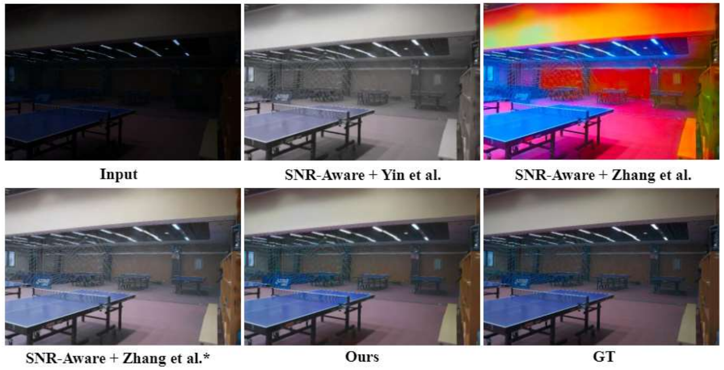


Figure 9: The qualitative comparison with "brighten-and-colorize" methods. Note that two brighteners have similar visual results, we only present the results of SNR-Aware [41].

Experiments

Table 3: Ablation studies on LOL-real [43] dataset. The best results are boldfaced and the second-best ones are underlined.

Methods	PSNR ↑	SSIM ↑	CSE(ratio) ↓	Size (M)
W/o Decoupling	21.28	0.8003	3.05	4.22
W/o Sharing	23.03	0.8591	1.12	8.44
W/o LAM	22.77	0.8516	**0.91**	6.84
W/o CEM	23.06	0.8575	1.66	6.84
W/o $\mathcal{L}_q$	23.21	0.8600	1.11	6.84
Ours	**23.27**	**0.8637**	1.00	6.84

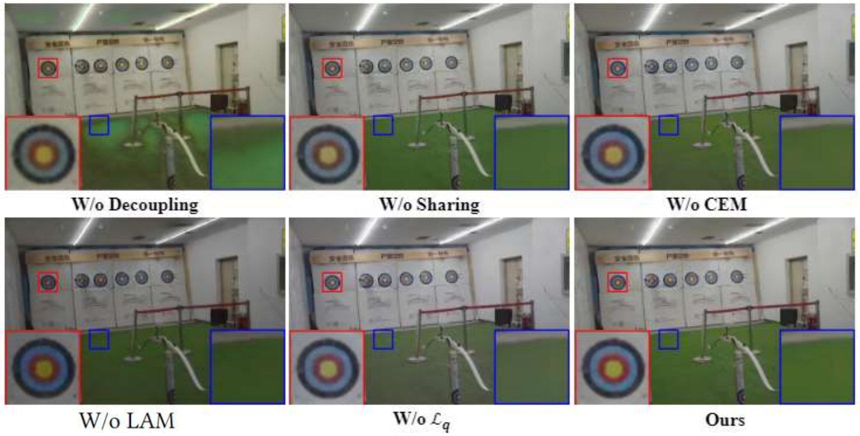


Figure 10: The qualitative comparison of ablation studies.

Table 6: Results of the color space ablation studies on LOL-real [43] dataset. The best results are boldfaced and the second-best ones are underlined.

Methods	PSNR	SSIM	LPIPS	CSE (ratio)
HSV	22.02	0.8257	0.0809	1.12
HLS	22.31	0.8454	0.0869	1.38
Luv	22.02	0.8420	0.0702	1.06
Yuv	22.37	0.8416	0.0751	1.16
Lab (ours)	**23.21**	**0.8600**	**0.0619**	**1.00**

Thanks!