Supplementary Material

Underwater Image Color Correction using Exposure-Bracketing Imaging

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We first show visual comparisons in color correction of underwater images for all of the scenes we recorded: "S1" through "S6". We compared our method with the following state-of-the-art methods: Wen *et al.* [1], Berman *et al.* [2], Iqbal *et al.* [3], Ancuti *et al.* [4], Fu *et al.* [5], GrayWorld [6], Yang *et al.* [7], and Nomura *et al.* [8]; they are the same as those reported in the submitted paper.

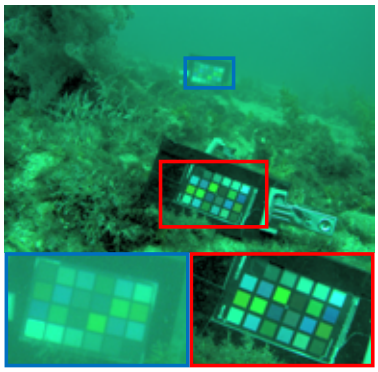
We then show reconstructed images obtained using our method with varying the parameters (S, th and α).

1. Visual Comparisons

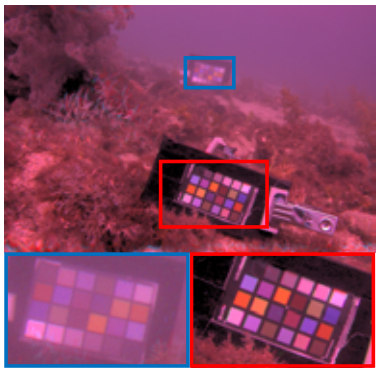
Visual comparisons in color correction of underwater images

(scene "**S1**")

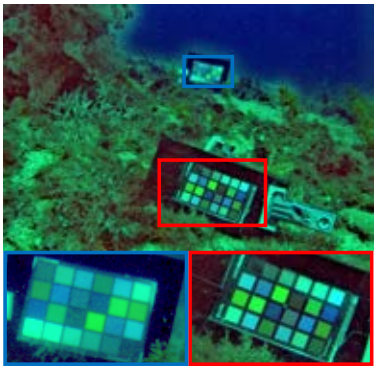
We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.



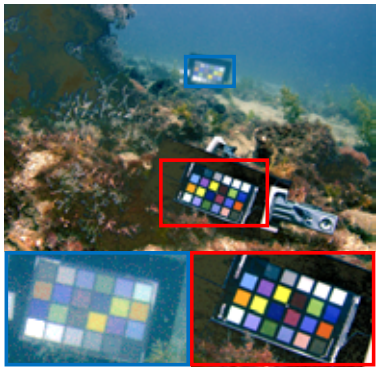
Input underwater image



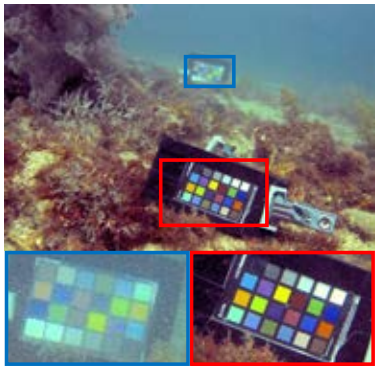
Fused image **H**



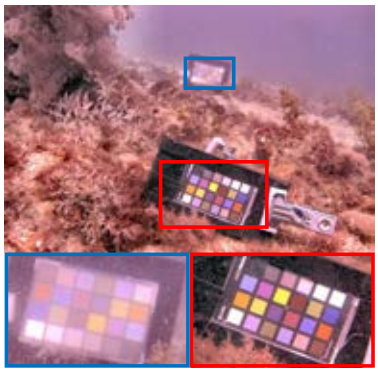
Wen *et al.* [1]
Far : 55.69 Near : 52.13



Berman *et al.* [2]
Far : 15.32 Near : 20.63

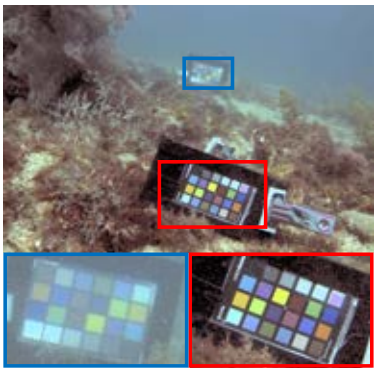


Iqbal *et al.* [3]
Far : 18.98 Near : 17.41

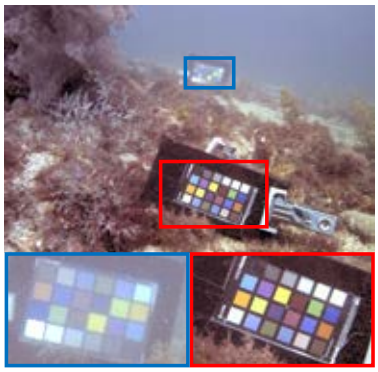


Ancuti *et al.* [4]
Far : 24.08 Near : 22.82

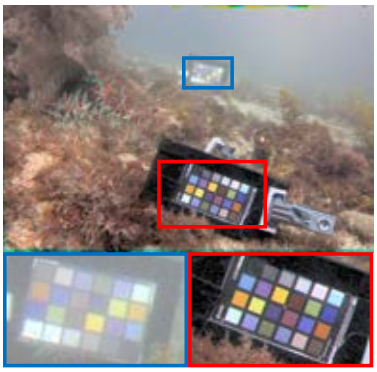
Fu *et al.* [5]
Far : 30.00 Near : 23.84



GrayWorld [6]
Far : 17.81 Near : 14.59



Yang *et al.* [9]
Far : 17.48 Near : 16.31



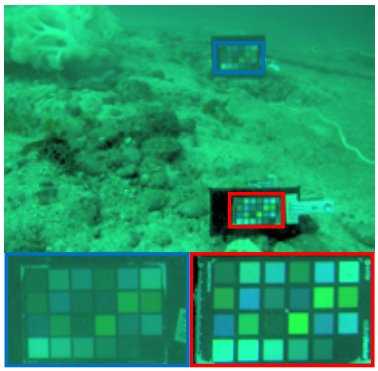
Nomura *et al.* [8]
Far : 14.44 Near : 12.63

Ours
Far : **13.99** Near : **11.66**

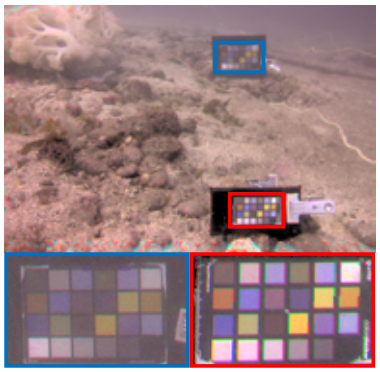
Visual comparisons in color correction of underwater images

(scene "**S2**")

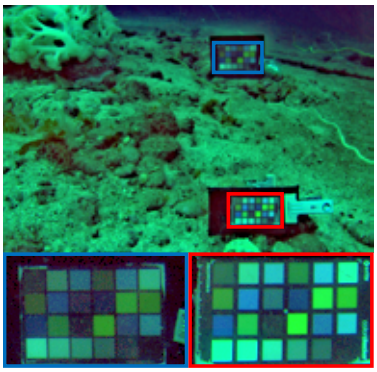
We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.



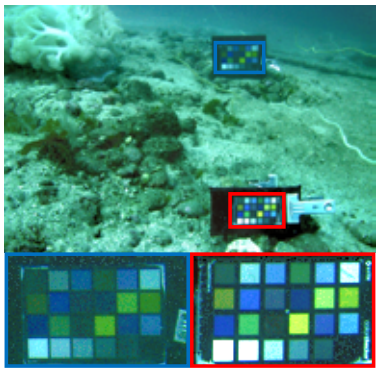
Input underwater image



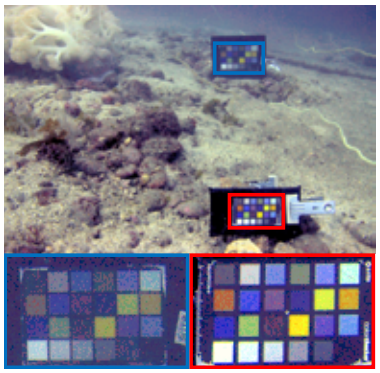
Fused image **H**



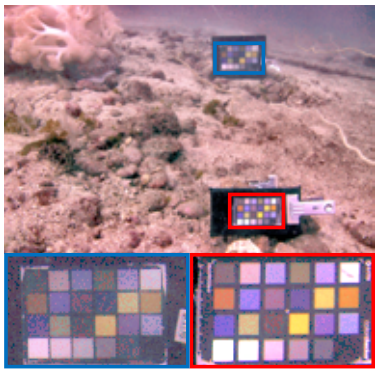
Wen *et al.* [1]
Far : 41.52 Near : 52.34



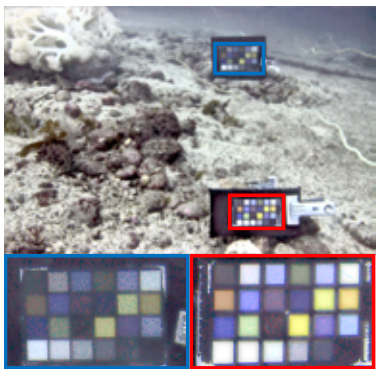
Berman *et al.* [2]
Far : 50.51 Near : 28.23



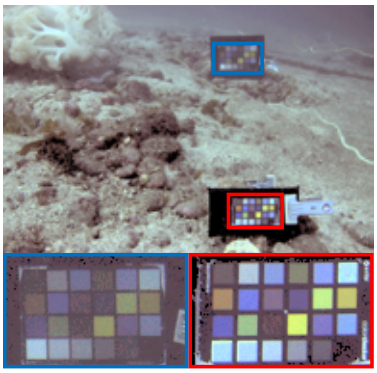
Iqbal *et al.* [3]
Far : 33.53 Near : 20.80



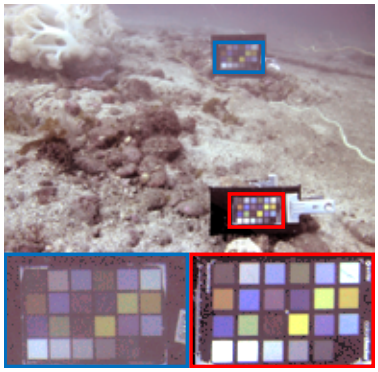
Ancuti *et al.* [4]
Far : 28.00 Near : 22.72



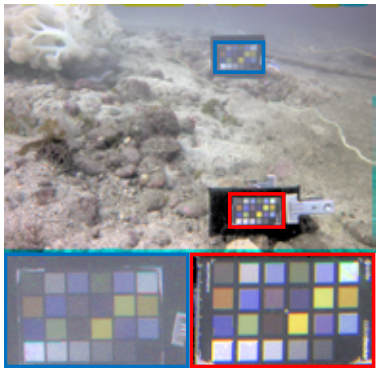
Fu *et al.* [5]
Far : 29.56 Near : 23.13



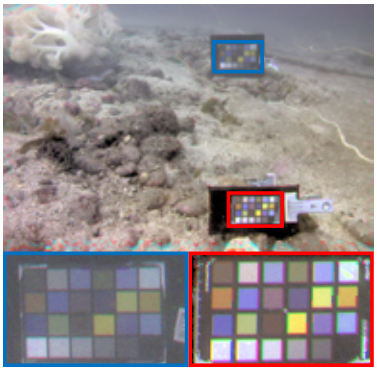
GrayWorld [6]
Far : 27.40 Near : 18.34



Yang *et al.* [9]
Far : 27.05 Near : 19.19



Nomura *et al.* [8]
Far : 27.48 Near : 15.10

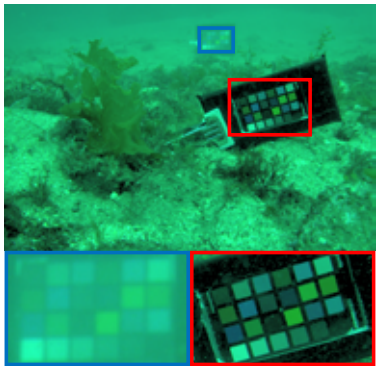


Ours
Far : **27.02** Near : **14.99**

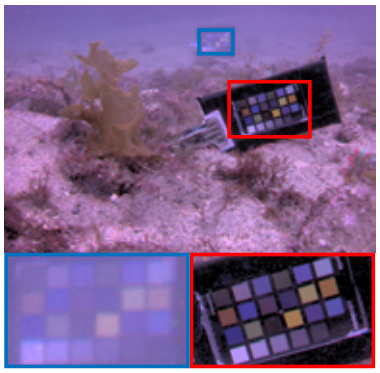
Visual comparisons in color correction of underwater images

(scene "**S3**")

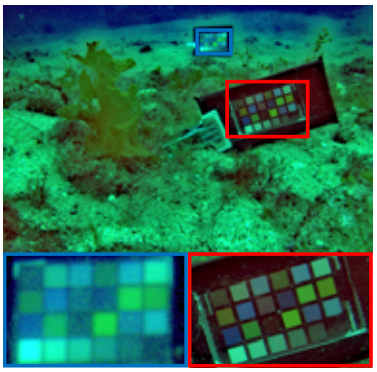
We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.



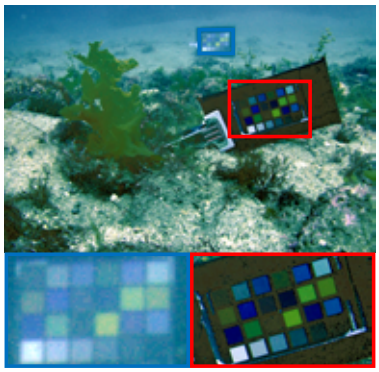
Input underwater image



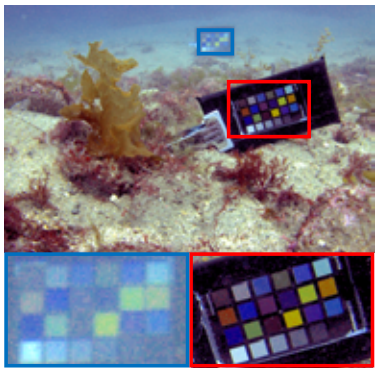
Fused image **H**



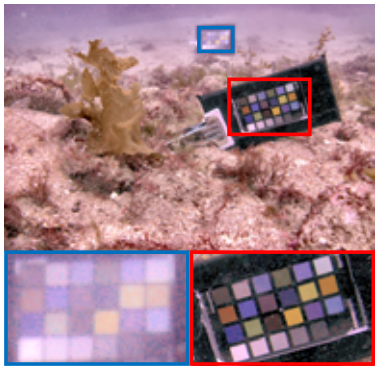
Wen *et al.* [1]
Far : 57.11 Near : 35.52



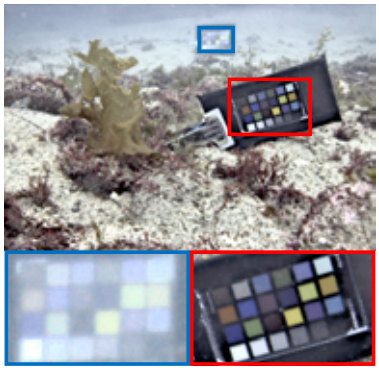
Berman *et al.* [2]
Far : 31.86 Near : 43.03



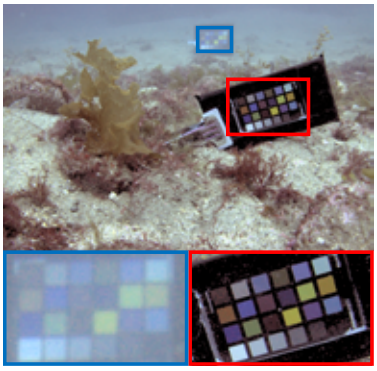
Iqbal *et al.* [3]
Far : 29.37 Near : 26.04



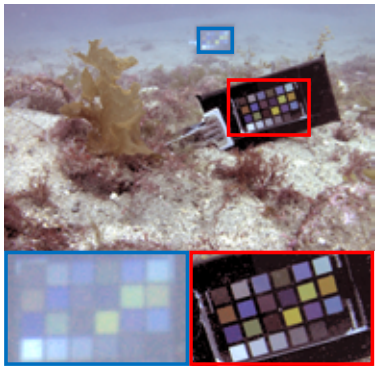
Ancuti *et al.* [4]
Far : 21.66 Near : 16.37



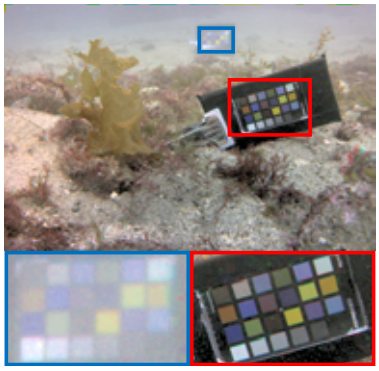
Fu *et al.* [5]
Far : 24.94 Near : 19.66



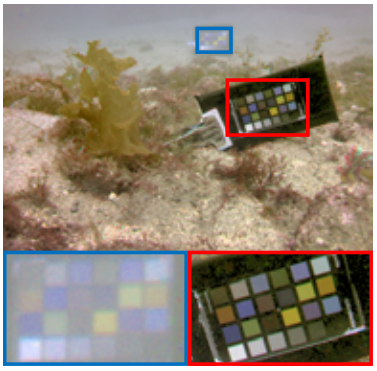
GrayWorld [6]
Far : 24.07 Near : 16.75



Yang *et al.* [9]
Far : 23.84 Near : 16.40



Nomura *et al.* [8]
Far : **18.65** Near : 16.15

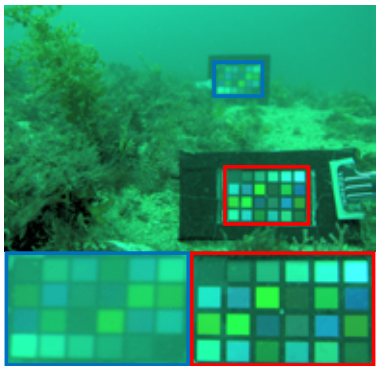


Ours
Far : 19.02 Near : **15.46**

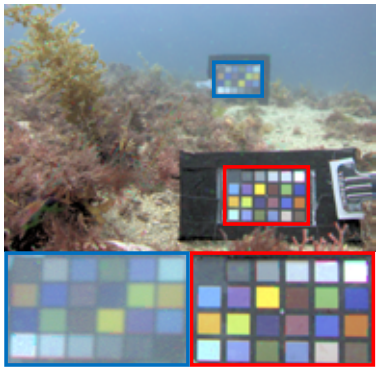
Visual comparisons in color correction of underwater images

(scene "**S4**")

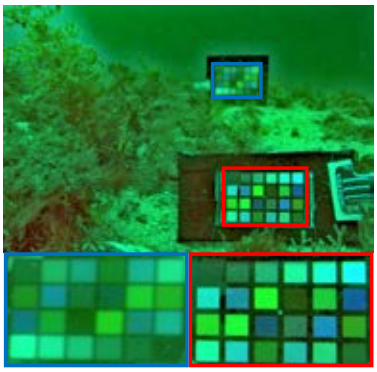
We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.



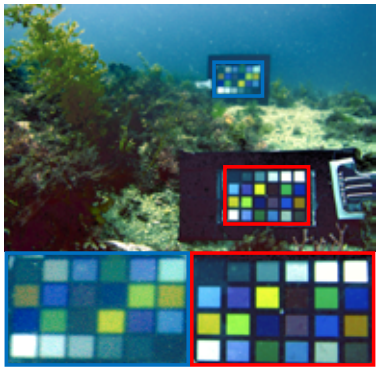
Input underwater image



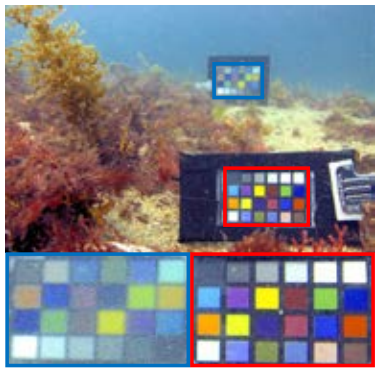
Fused image **H**



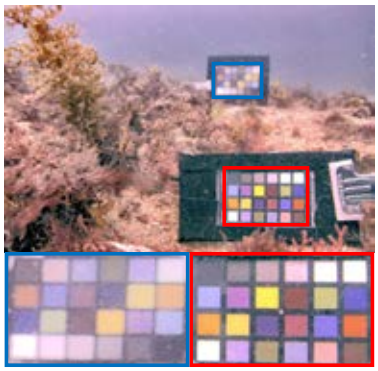
Wen *et al.* [1]
Far : 55.90 Near : 52.95



Berman *et al.* [2]
Far : 31.58 Near : 25.50

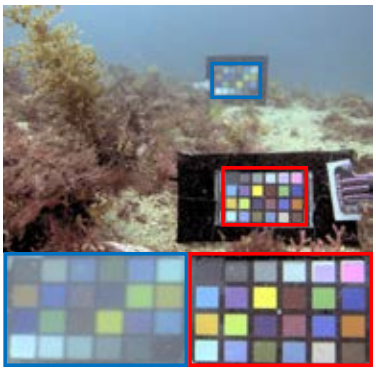


Iqbal *et al.* [3]
Far : 19.84 Near : 19.50

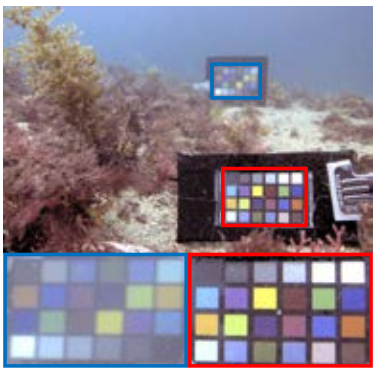


Ancuti *et al.* [4]
Far : 20.27 Near : 20.17

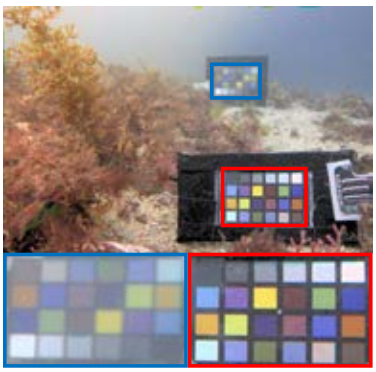
Fu *et al.* [5]
Far : 23.65 Near : 23.01



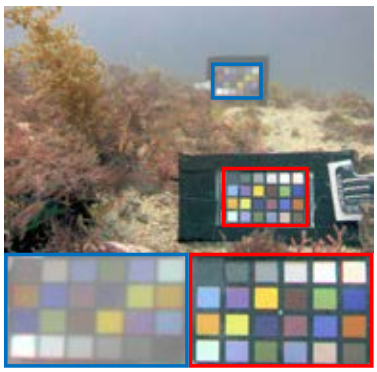
GrayWorld [6]
Far : 19.29 Near : 14.35



Yang *et al.* [9]
Far : 19.77 Near : 15.80

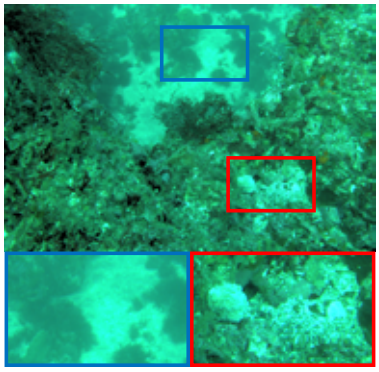


Nomura *et al.* [8]
Far : 16.41 Near : 13.84

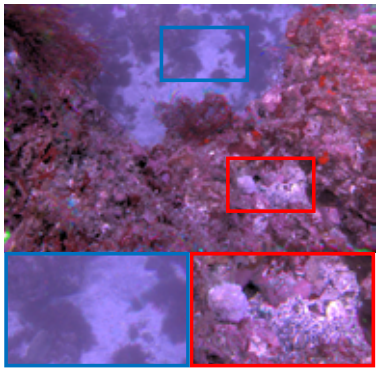


Ours
Far : **14.31** Near : **12.83**

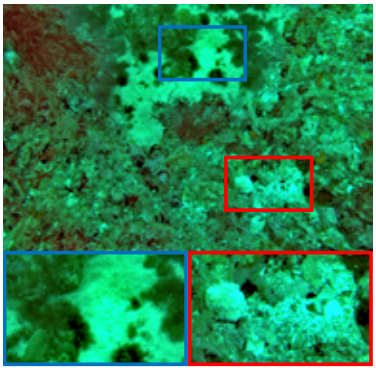
Visual comparisons in color correction of underwater images (scene "**S5**")



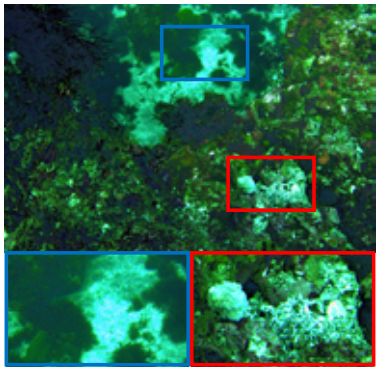
Input underwater image



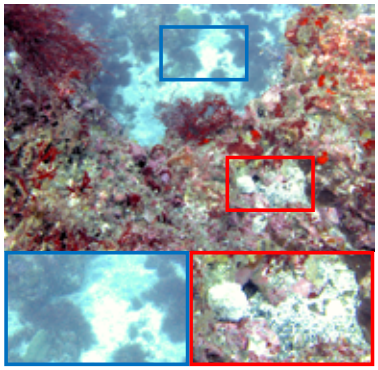
Fused image **H**



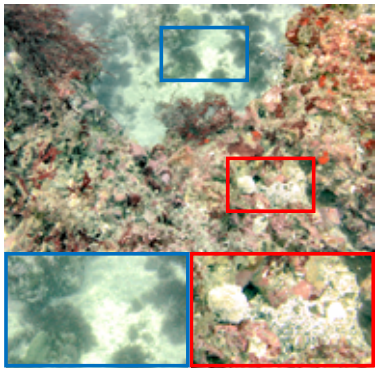
Wen *et al.* [1]



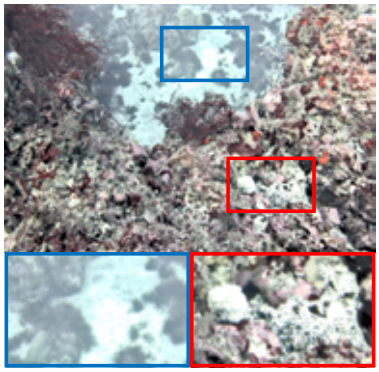
Berman *et al.* [2]



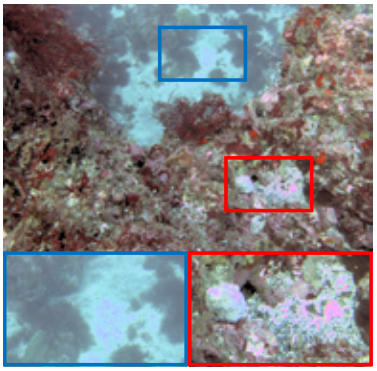
Iqbal *et al.* [3]



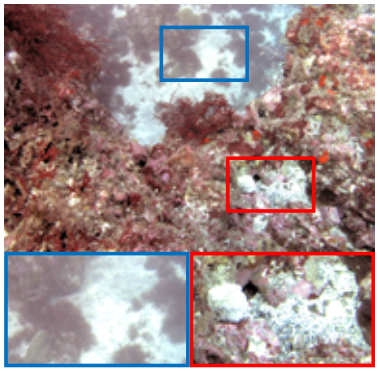
Ancuti *et al.* [4]



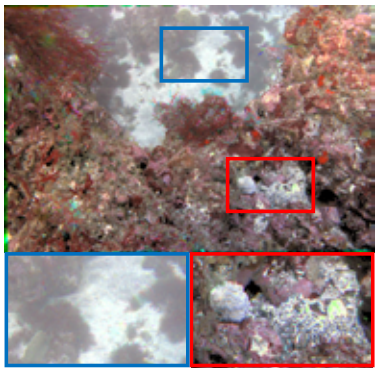
Fu *et al.* [5]



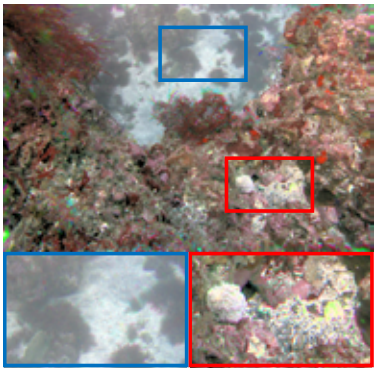
GrayWorld [6]



Yang *et al.* [9]

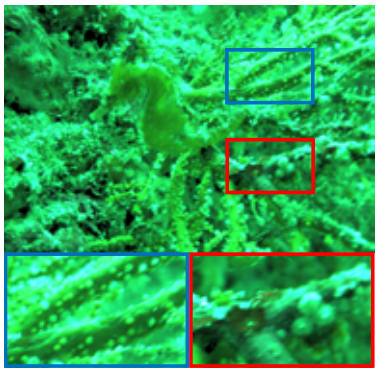


Nomura *et al.* [8]

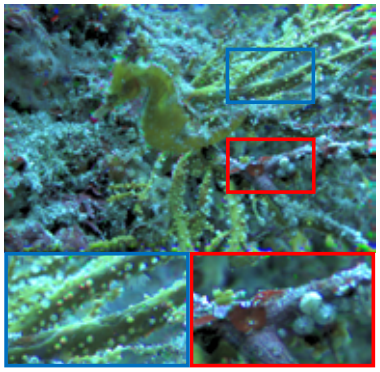


Ours

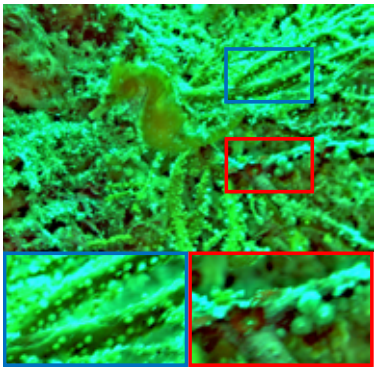
Visual comparisons in color correction of underwater images (scene "**S6**")



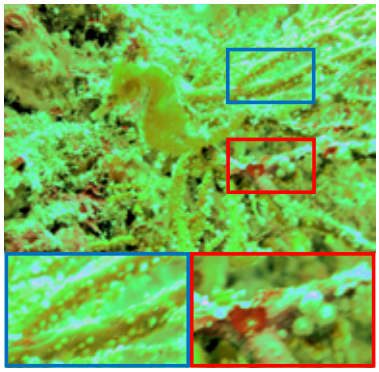
Input underwater image



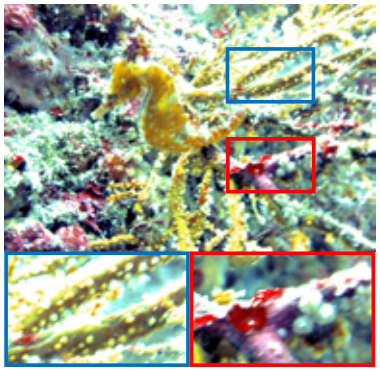
Fused image **H**



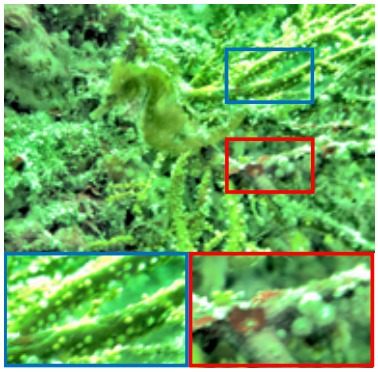
Wen *et al.* [1]



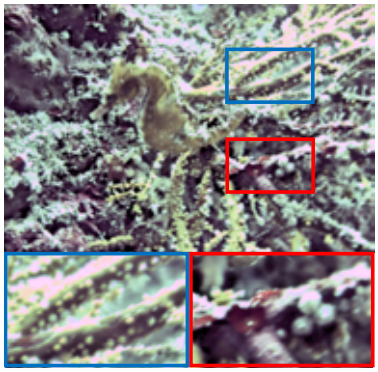
Berman *et al.* [2]



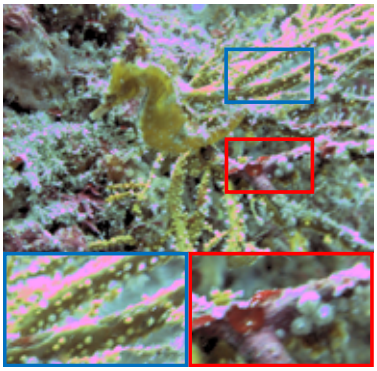
Iqbal *et al.* [3]



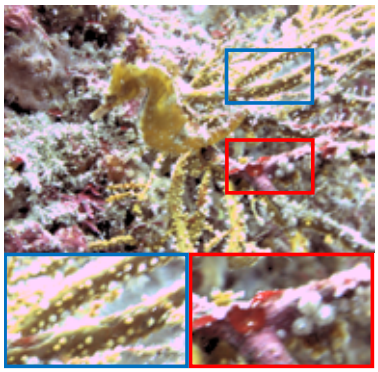
Ancuti *et al.* [4]



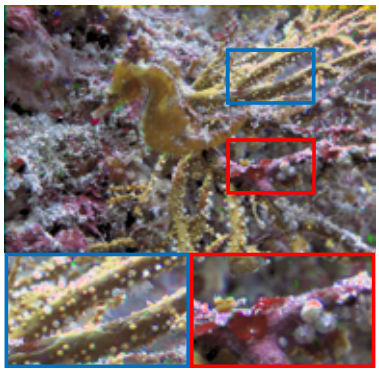
Fu *et al.* [5]



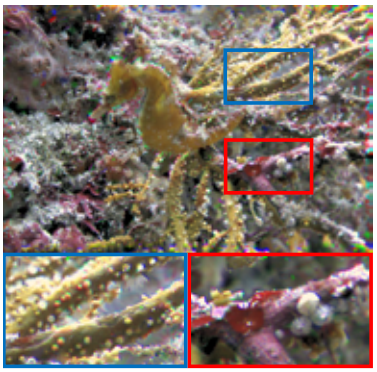
GrayWorld [6]



Yang *et al.* [9]



Nomura *et al.* [8]



Ours

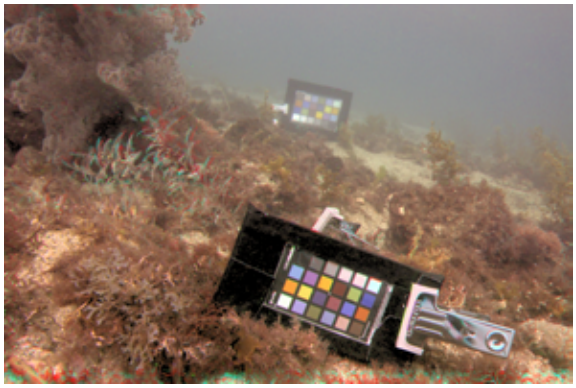
2. Results with Varying Parameters

Influences of varying ***th***

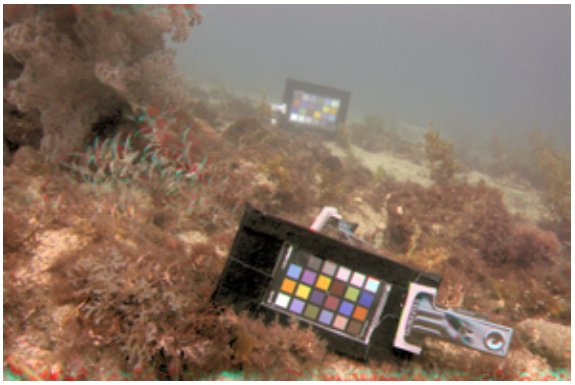
for scene "S1"

We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.

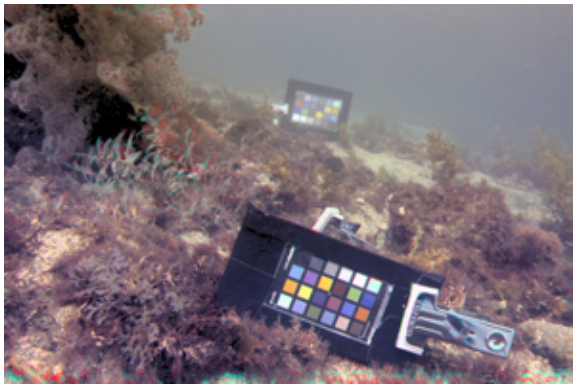
$th = 0.26$
Far : 14.05 Near : 11.74



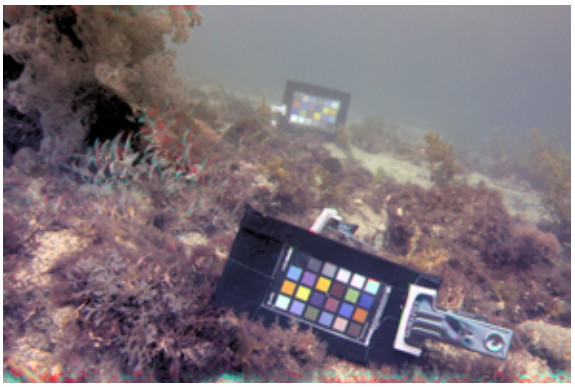
$th = 0.27$
Far : 14.05 Near : 11.67



$th = 0.30$
Far : **13.99** Near : **11.66**



$th = 0.33$
Far : 14.04 Near : 13.00

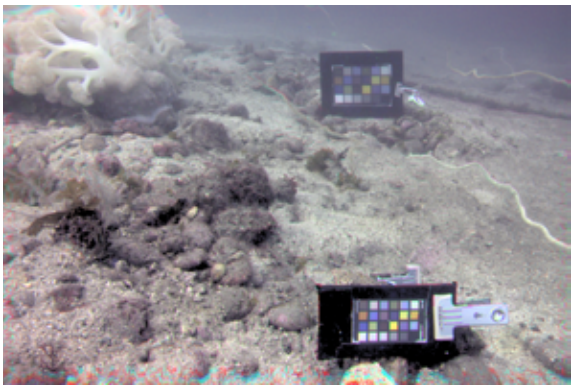


$th = 0.39$
Far : 14.05 Near : 13.01

Influences of varying $\boldsymbol{S}$

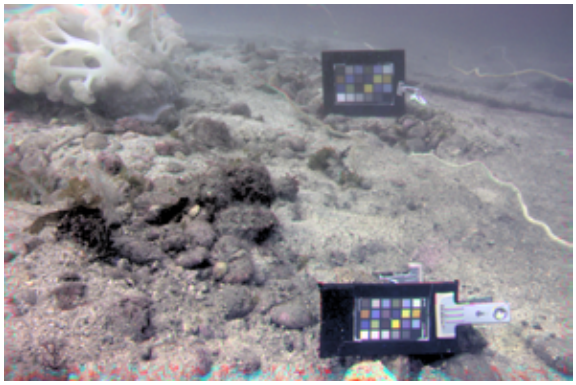
for scene "S2"

We respectively show the CIEDE2000 values measured in "Far" and "Near" regions in each image.



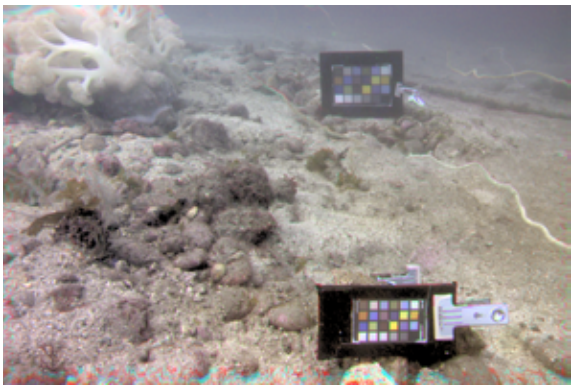
$S = 1$

Far : 29.93 Near : 17.85



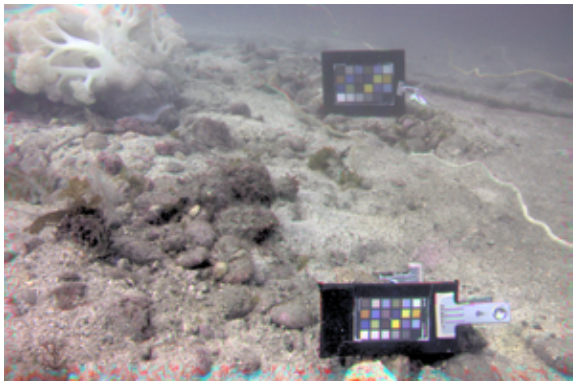
$S = 3$

Far : 30.18 Near : 18.01



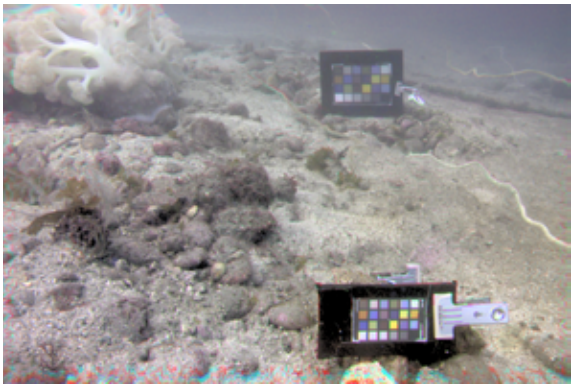
$S = 5$

Far : **27.02** Near : **14.99**



$S = 7$

Far : 28.00 Near : 16.58

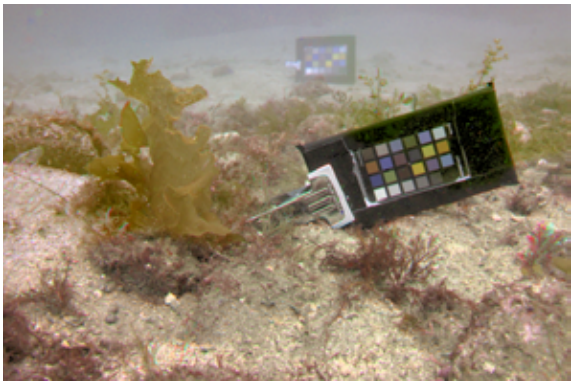


$S = 9$

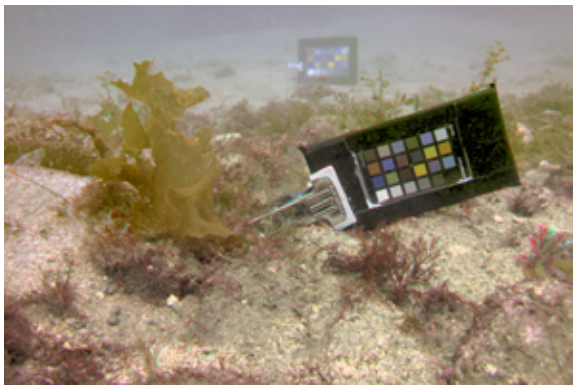
Far : 27.98 Near : 15.82

Influences of varying $\boldsymbol{\alpha}$

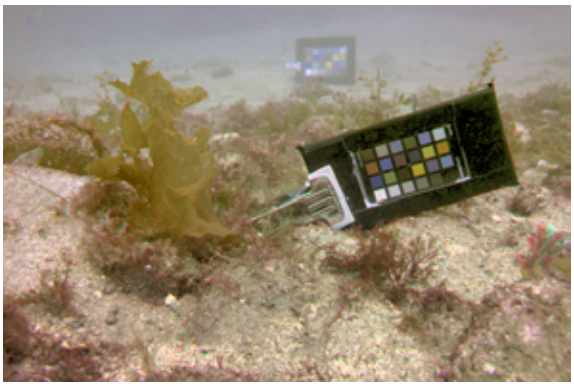
for scene "S3"



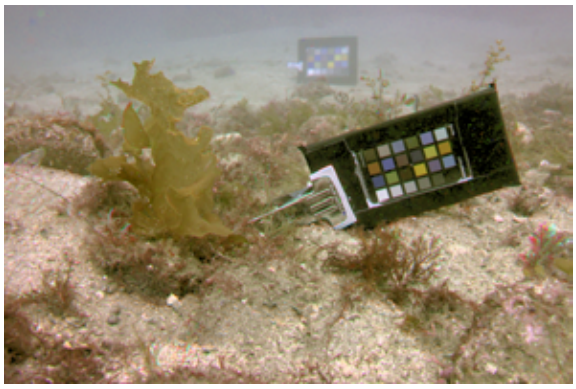
$\alpha = 0.05$



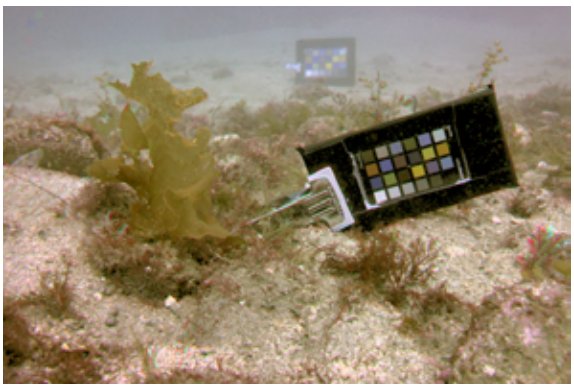
$\alpha = 0.1$



$\alpha = 0.2$



$\alpha = 0.4$



$\alpha = 0.8$

References

[1] H. Wen, Y. Tian, T. Huang, and W. Gao, "Single underwater image enhancement with a new optical model," in *IEEE ISCAS*, 2013, pp. 753–756.

[2] D. Berman, T. Treibitz, and S. Avidan, "Diving into haze-lines: color restoration of underwater images," in *BMVC*, 2017.

[3] K. Iqbal, M. James, R. Salam, and A. Talib, "Enhancing the low quality images using unsupervised colour correction method," in *IEEE SMC*, 2010, pp. 1703–1709.

[4] C. Ancuti, C. Ancuti, T. Haber, and P. Bekaert, "Enhancing underwater images and videos by fusion," in *IEEE CVPR*, 2012, pp. 81–88.

[5] X. Fu, P. Zhuang, Y. Huang, Y. Liao, and X. Zhang, "A retinex-based enhancing approach for single underwater image," in *IEEE ICIP*, 2014, pp. 4572–4576.

[6] G. Buchsbaum, "A spatial processor model for object colour perception," *Journal of The Franklin Institute*, vol. 310, pp. 1–26, 1980.

[7] H. Yang, P. Chen, C. Huang, Y. Zhuang, and Y. Shiau, "Low complexity underwater image enhancement based on dark channel prior," in *IEEE IBICA*, 2011, pp. 17–20.

[8] K. Nomura, D. Sugimura, and T. Hamamoto, "Color correction of underwater images based on multi-illuminant estimation with exposure bracketing imaging," in *IEEE ICIP*, 2017, pp. 705–709.

[9] K. Yang, S. Gao, and Y. Li, "Efficient illuminant estimation for color constancy using gray pixels," in *IEEE CVPR*, 2015, pp. 2254–2263.