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COLOR CORRECTION OF UNDERWATER IMAGES USING COLOR CHANNEL PRIOR

Zihan Zhang, Kohei Inoue* and Kenji Hara

Faculty of Design
Kyushu University
4-9-1 Shiobaru, Minami-ku, Fukuoka 815-8540, Japan
zzh_2150@163.com; hara@design.kyushu-u.ac.jp
*Corresponding author: k-inoue@design.kyushu-u.ac.jp

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Abstract. *The purpose of this study is to introduce a novel prior, and demonstrate its effectiveness in underwater image enhancement. In this paper, we propose a prior that the minimum and maximum values of each of RGB color channels in a scene under a white light source are almost the same as the minimum and maximum values of possible pixel values, and call it color channel prior (CCP). We also combine the proposed CCP with gray world assumption (GWA), and use it for color correction of underwater images. Experimental results demonstrate that the proposed method can enhance the contrast of underwater images by using CCP, and reduce bluish color deviation by using GWA.*
Keywords: Color correction, Underwater images, Color channel prior, Gray world assumption

1. **Introduction.** Image enhancement is one of the most important technologies in image processing and related fields, and has been comprehensively reviewed by researchers [1, 2]. General-purpose methods for image enhancement such as histogram equalization [3] and gamma correction [4] may fail to enhance some exceptional images such as underwater images [5] and haze images [6].

For example of those specific image enhancement, He et al. [6] proposed dark channel prior (DCP) for single image haze removal. Owing to the effectiveness of DCP in dehazing, the majority of recent dehazing techniques, including video dehazing [7], have adopted the DCP [8]. In spite of the effectiveness of DCP in dehazing, it is difficult to use DCP directly for underwater image enhancement, because DCP assumes that the backscatter component is white, which is true in air, but the heavy attenuation underwater causes the red wavelength to disappear very quickly [9]. There are attempts to adjust DCP to underwater images such as underwater DCP (UDCP) [10], red-DCP (RDCP) [11] and underwater-ready DCP [9]. However, the estimated transmission maps are still not correct. Moreover, those DCP-based methods are patch-based ones. Therefore, it is necessary to refine the transmission maps to reduce artificial block effects by using soft matting [12] and bilateral filter [13].

Inspired by the success and drawbacks of the DCP, in this paper, we propose a novel prior for scene images taken under a white light source, and call it *color channel prior* (CCP). We apply the proposed CCP to underwater image enhancement, where a given underwater image is assumed to not satisfy CCP because we know by experience that underwater images often have bluish appearance. Then we transform the given underwater image into another that satisfies CCP. Our preliminary experiments revealed that the resultant images were sometimes still bluish. To reduce the remaining bluish color

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deviation, we combine gray world assumption (GWA) [14] to the CCP procedure. As a result, we obtain the final image that satisfies both CCP and GWA.

The rest of this paper is organized as follows. Section 2 proposes CCP and CCP-based method for image enhancement. Section 3 proposes a method for combining GWA to the above method. Section 4 shows experimental results. Finally, Section 5 concludes this paper.

2. **Color Channel Prior.** Let $F_i = [\boldsymbol{f}_{ij}]$ for $i = 1, 2, \ldots, n$ be n scene images taken under a white light source, where $\boldsymbol{f}_{ij}$ denotes the RGB color vector of the jth pixel in F_i as $\boldsymbol{f}_{ij} = [r_{ij}, g_{ij}, b_{ij}]$ for $j = 1, 2, \ldots, m_i$, where m_i denotes the number of pixels in F_i. Assume that each element of $\boldsymbol{f}_{ij}$ is in the interval $[0, 1]$. Then we denote the minimum and maximum values in each color channel as follows:

$$r_i^{\min} = \min_j\{r_{ij}\}, \quad g_i^{\min} = \min_j\{g_{ij}\}, \quad b_i^{\min} = \min_j\{b_{ij}\}, \tag{1}$$

$$r_i^{\max} = \max_j\{r_{ij}\}, \quad g_i^{\max} = \max_j\{g_{ij}\}, \quad b_i^{\max} = \max_j\{b_{ij}\}. \tag{2}$$

If a scene of wide area is photographed under a white light source, then it is likely that a variety of colors are recorded in a color image with high contrast. This experience can be formulated as

$$r_i^{\min} \approx g_i^{\min} \approx b_i^{\min} \approx 0, \tag{3}$$

$$r_i^{\max} \approx g_i^{\max} \approx b_i^{\max} \approx 1, \tag{4}$$

and is called *color channel prior* (CCP).

From an RGB color image $F = [\boldsymbol{f}_j]$ with $\boldsymbol{f}_j = [r_j, g_j, b_j]$, we can make the color-corrected image that satisfies CCP as follows: Let $\hat{F} = \left[\hat{\boldsymbol{f}}_j\right]$ with $\hat{\boldsymbol{f}}_j = \left[\hat{r}_j, \hat{g}_j, \hat{b}_j\right]$ be the resultant color-corrected image computed from F. Then a component $\hat{x}_j \in \left\{\hat{r}_j, \hat{g}_j, \hat{b}_j\right\}$ in $\hat{\boldsymbol{f}}_j$ is given by

$$\hat{x}_j = \frac{x_j - x_{\min}}{x_{\max} - x_{\min}}, \tag{5}$$

where $x_j \in \{r_j, g_j, b_j\}$, $x_{\min} = \min_j\{x_j\}$ and $x_{\max} = \max_j\{x_j\}$. We can confirm that $\hat{F}$ satisfies CCP as $\min_j\{\hat{x}_j\} = \frac{x_{\min} - x_{\min}}{x_{\max} - x_{\min}} = 0$ and $\max_j\{\hat{x}_j\} = \frac{x_{\max} - x_{\min}}{x_{\max} - x_{\min}} = 1$.

3. **Combining Gray World Assumption.** The gray world assumption (GWA) states that the average illumination reflected by the objects in a scene under white light source is achromatic [14]. More specifically, if a color image $F = [\boldsymbol{f}_j]$ with $\boldsymbol{f}_j = [r_j, g_j, b_j]$ satisfies GWA, then we have $\bar{r} = \bar{g} = \bar{b}$, where $\bar{x} = \frac{1}{m}\sum_{j=1}^{m} x_j$ for each $x \in \{r, g, b\}$ where m denotes the number of pixels in F.

Generally, the color-corrected image $\hat{F}$ satisfying CCP does not satisfy GWA, because (5) is unrelated to the mean values of RGB color channels. In this section, we propose a method for generating a color image satisfying both CCP and GWA by using gamma correction [15].

Let $\tilde{x} = \frac{1}{m}\sum_{j=1}^{m} \hat{x}_j$ for $x \in \{r, g, b\}$ be the average pixel value of each color channel in $\hat{F}$. Then we select the maximum value $v = \max\left\{\tilde{r}, \tilde{g}, \tilde{b}\right\}$ as the target gray value of the resultant image satisfying GWA. For each color channel $\hat{x}_j \in \left\{\hat{r}_j, \hat{g}_j, \hat{b}_j\right\}$ of $\hat{F}$, we solve the following minimization problem:

$$\min_{\gamma} \quad \left(\frac{1}{m}\sum_{j=1}^{m} \hat{x}_j^{\gamma} - v\right)^2 \tag{6}$$

to obtain an optimum γ value. Let $E(\gamma)$ be the objective function in (6). Then we have

$$\frac{\partial E}{\partial \gamma} = 2\left(\frac{1}{m}\sum_{j=1}^{m}\hat{x}_j^{\gamma} - v\right)\left(\frac{1}{m}\sum_{j=1}^{m}\hat{x}_j^{\gamma}\ln\hat{x}_j\right), \tag{7}$$

which is used for the following gradient method:

$$\gamma^{(t+1)} = \gamma^{(t)} - \alpha \left.\frac{\partial E}{\partial \gamma}\right|_{\gamma=\gamma^{(t)}}, \tag{8}$$

where α denotes a positive constant, $\left.\frac{\partial E}{\partial \gamma}\right|_{\gamma=\gamma^{(t)}}$ denotes a value of (7) into which $\gamma = \gamma^{(t)}$ is substituted, and the superscript $t = 0, 1, 2, \ldots$ denotes the number of iterations, which produce a sequence $\gamma^{(1)}, \gamma^{(2)}, \ldots$ from a given initial value $\gamma^{(0)}$.

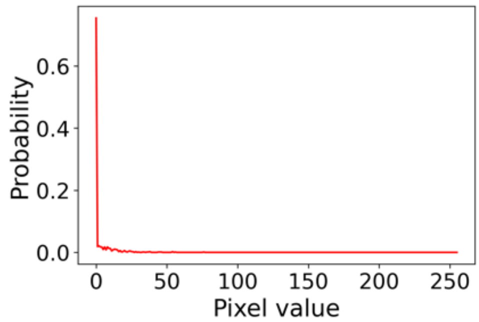
4. **Experimental Results.** We examined the validity of CCP with the VOC 2005 Database: Testset 2 [16], which includes 859 images as shown in Figure 1.

FIGURE 1. Examples in the VOC 2005 Database: Testset 2 [16]

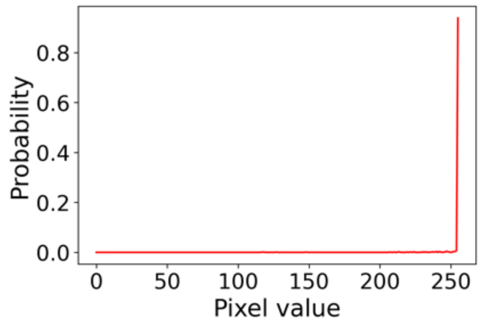
Figure 2 shows the existence probabilities of minimum and maximum RGB values in the dataset, where the vertical and horizontal axes denote the probability and pixel value represented by 8-bit integers ranging from 0 to 255, i.e., $2^8 - 1$. Figures 2(a), 2(c) and 2(e) in the left column show the distribution of the minimum values in R, G and B channels, respectively, where the respective peaks are located at 0 on the horizontal axes. On the other hand, Figures 2(b), 2(d) and 2(f) in the right column show the distribution of the maximum values in R, G and B channels, respectively, where the respective peaks are located at 255 on the horizontal axes. These results support that CCP in (3) and (4) is valid for the dataset.

Next, we show a result of color correction given by the proposed method applied to an image in the Underwater Image Enhancement Benchmark (UIEB) Dataset [17] in Figure 3, where Figure 3(a) shows an original image, the color of which is corrected to satisfy CCP by (5) as shown in Figure 3(b). Although the color-corrected image in Figure 3(b) has higher contrast than the original image in Figure 3(a), it seems to be still bluish. To reduce such color deviation to blue, we also combine GWA as described in Section 3. Figure 3(c) shows the final result, where the bluish color deviation is reduced compared with Figure 3(b).

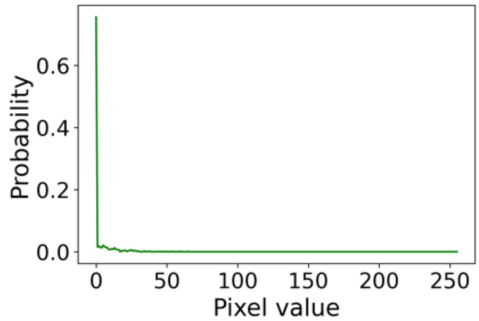
In this example, B channel is selected as the maximum average pixel value as $v = \max\left\{\tilde{r}, \tilde{g}, \tilde{b}\right\} = \tilde{b}$. Then we apply gamma correction to R and G channels to achieve



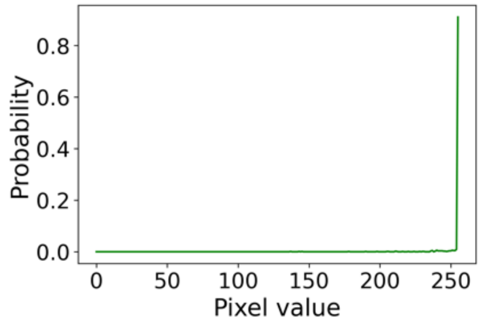
(a) Minimum R values



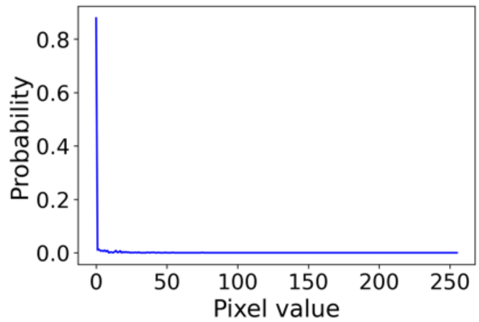
(b) Maximum R values



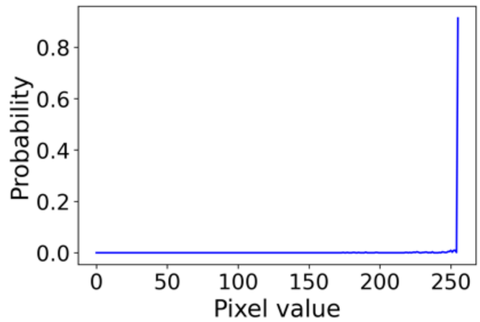
(c) Minimum G values



(d) Maximum G values



(e) Minimum B values



(f) Maximum B values

FIGURE 2. Existence probabilities of minimum and maximum values in RGB channels

(a) Original

(b) CCP

(c) CCP+GWA

FIGURE 3. Color correction of an underwater image in UIEB [17]

GWA. Figure 4 shows the change of the gamma values for R and G channels by the iterations in the gradient method in (8), where we used $\alpha = 1$ and $\gamma^{(0)} = 1$. The gamma values sufficiently converged in 10 iterations.

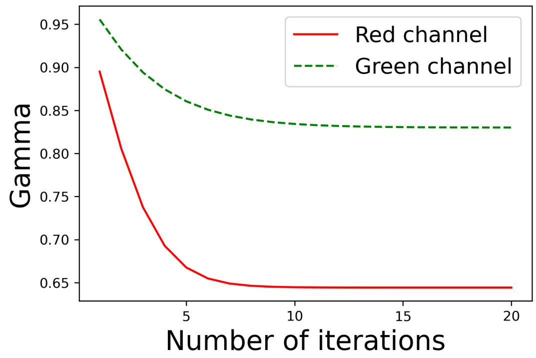


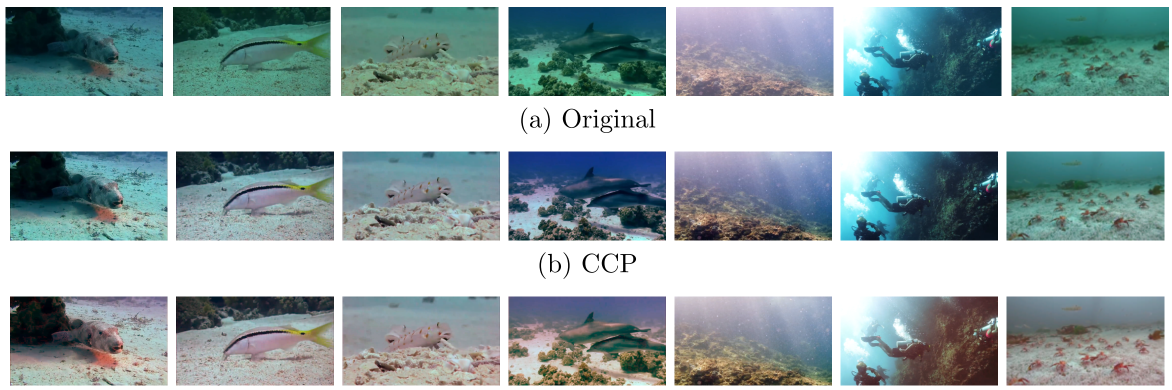
FIGURE 4. Value of $\gamma^{(t)}$ vs. number of iterations t

Table 1 shows average pixel values of the images in Figure 3, where the original image in Figure 3(a) corresponding to the first row satisfies neither CCP nor GWA as denoted by two '×'s in the right two columns having headers 'CCP' and 'GWA'. On the other hand, the color-corrected image in Figure 3(b) corresponding to the second row satisfies CCP but not GWA as denoted by '○' and '×', and further improved image in Figure 3(c) corresponding to the third row satisfies both CCP and GWA as denoted by two '○'s. The satisfaction of both CCP and GWA indicates the successful results of underwater image enhancement.

TABLE 1. Average pixel values

	R	G	B	CCP	GWA
Original (Figure 3(a))	45.9	162.8	171.4	×	×
CCP (Figure 3(b))	77.6	100.3	116.6	○	×
CCP+GWA (Figure 3(c))	116.6	116.6	116.6	○	○

Figure 5 shows additional results of color correction with UIEB [17], where we observe that the contrast of original images in 5(a) are enhanced by using CCP as shown in 5(b), and the bluish color deviation remaining in 5(b) is reduced by combining GWA as shown in 5(c).



(a) Original

(b) CCP

(c) CCP+GWA

FIGURE 5. Color correction of underwater images in UIEB [17]

5. **Conclusions.** In this paper, we proposed a method for correcting the color of underwater images by using color channel prior (CCP), which was demonstrated with a publicly available dataset (VOC 2005 [16]). By the proposed method, a given image is linearly transformed to satisfy CCP, which can reduce bluish color deviation observed in

underwater images. We also combined gray world assumption (GWA) with CCP, where a gamma correction method is applied to each color channel of given image. The parameter of gamma correction is optimized with a gradient method to ensure GWA. This combination of CCP and GWA further improves the visibility of underwater images. In our experiments with an underwater image dataset (UIEB [17]), we observed that the contrast of underwater images was enhanced, and bluish color deviation was reduced with both CCP and GWA.

Our future work will include the application of the proposed method to low-light image enhancement [18].

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REFERENCES

[1] G. Singh and A. Mittal, Various image enhancement techniques – A critical review, *International Journal of Innovation and Scientific Research*, vol.10, no.2, pp.267-274, http://www.ijisr.issr-journals.org/abstract.php?article=IJISR-14-227-01#google_vignette, 2014.

[2] Y. Qi, Z. Yang, W. Sun et al., A comprehensive overview of image enhancement techniques, *Arch. Computat. Methods Eng.*, vol.29, pp.583-607, https://doi.org/10.1007/s11831-021-09587-6, 2022.

[3] W. A. Mustafa and M. M. M. Abdul Kader, A review of histogram equalization techniques in image enhancement application, *J. Phys.: Conf. Ser.*, vol.1019, 012026, https://doi.org/10.1088/1742-6596/1019/1/012026, 2018.

[4] S. Rahman, M. M. Rahman, M. Abdullah-Al-Wadud et al., An adaptive gamma correction for image enhancement, *J. Image Video Proc.*, 35, https://doi.org/10.1186/s13640-016-0138-1, 2016.

[5] S. Mohan and P. Simon, Underwater image enhancement based on histogram manipulation and multiscale fusion, *Procedia Computer Science*, vol.171, pp.941-950, https://doi.org/10.1016/j.procs.2020.04.102, 2020.

[6] K. He, J. Sun and X. Tang, Single image haze removal using dark channel prior, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol.33, no.12, pp.2341-2353, https://doi.org/10.1109/TPAMI.2010.168, 2011.

[7] C.-C. Tsai, C.-Y. Lin and J.-I. Guo, Dark channel prior based video dehazing algorithm with sky preservation and its embedded system realization for ADAS applications, *Opt. Express*, vol.27, pp.11877-11901, https://doi.org/10.1364/OE.27.011877, 2019.

[8] S. Lee, S. Yun, J. H. Nam et al., A review on dark channel prior based image dehazing algorithms, *J. Image Video Proc.*, 4, https://doi.org/10.1186/s13640-016-0104-y, 2016.

[9] T. Łuczyński and A. Brik, Underwater image haze removal and color correction with an underwater-ready dark channel prior, *arXiv:1807.04169v1 [cs.CV]*, https://doi.org/10.48550/arXiv.1807.04169, 2018.

[10] P. Drews Jr, E. do Nascimento, F. Moraes, S. Botelho and M. Campos, Transmission estimation in underwater single images, *2013 IEEE International Conference on Computer Vision Workshops*, Sydney, NSW, Australia, pp.825-830, https://doi.org/10.1109/ICCVW.2013.113, 2013.

[11] C.-Y. Cheng, C.-C. Sung and H.-H. Chang, Underwater image restoration by red-dark channel prior and point spread function deconvolution, *2015 IEEE International Conference on Signal and Image Processing Applications (ICSIPA)*, Kuala Lumpur, Malaysia, pp.110-115, https://doi.org/10.1109/ICSIPA.2015.7412173, 2015.

[12] A. Levin, D. Lischinski and Y. Weiss, A closed-form solution to natural image matting, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol.30, no.2, pp.228-242, https://doi.org/10.1109/TPAMI.2007.1177, 2008.

[13] C. Tomasi and R. Manduchi, Bilateral filtering for gray and color images, *The 6th International Conference on Computer Vision (IEEE Cat. No.98CH36271)*, Bombay, India, pp.839-846, https://doi.org/10.1109/ICCV.1998.710815, 1998.

[14] J. Cepeda-Negrete and R. E. Sanchez-Yanez, Gray-world assumption on perceptual color spaces, in *Image and Video Technology. PSIVT 2013. Lecture Notes in Computer Science*, R. Klette, M. Rivera and S. Satoh (eds.), vol.8333, Springer, Berlin, Heidelberg, https://doi.org/10.1007/978-3-642-53842-1_42, 2014.

[15] G. Deng, A generalized gamma correction algorithm based on the SLIP model, *EURASIP J. Adv. Signal Process.*, 69, https://doi.org/10.1186/s13634-016-0366-7, 2016.

[16] M. Everingham et al., The 2005 PASCAL visual object classes challenge, *Proc. of the 1st International Conference on Machine Learning Challenges: Evaluating Predictive Uncertainty, Visual Object Classification, and Recognising Textual Entailment*, pp.117-176, http://host.robots.ox.ac.uk/pascal/VOC/databases.html#VOC2005_2, 2006.
[17] C. Li et al., An underwater image enhancement benchmark dataset and beyond, *IEEE Transactions on Image Processing*, vol.29, pp.4376-4389, https://doi.org/10.1109/TIP.2019.2955241, 2020. UIEB (Underwater Image Enhancement Benchmark Dataset), https://li-chongyi.github.io/proj_benchmark.html.
[18] W. Wang, X. Wu, X. Yuan and Z. Gao, An experiment-based review of low-light image enhancement methods, *IEEE Access*, vol.8, pp.87884-87917, https://doi.org/10.1109/ACCESS.2020.2992749, 2020.