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Evaluation of the Effect of Paints Reproducing Ocean Color in Visible Light Range

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Abstract. In order to achieve the goal that the paints can reproduce the real ocean color, the color reproduction effect of paints is evaluated in this paper. 15 paint blocks and three standard sea spectra including coastal water, medium sea and high sea were selected as experimental samples. The spectral reflectance of paints was measured by X-Rite Color-Eye 7000A spectrophotometer, which were used as the experimental data samples. Then the chromaticity value and spectral evaluation index of paint colors and ocean colors were calculated by using D65 light source and tristimulus value under 10 degree viewing field. At last, from the aspects of chroma and spectra, the analysis and evaluation were carried out. The evaluation results show that the combination of chroma evaluation and spectral accuracy evaluation can accurately evaluate the effect of paints reproducing marine color, which is of great significance to produce the paints reproducing real ocean color.

1. Introduction

In the visible light range, the paints used to reproduce the ocean color on the surface of ships can achieve the purpose of mixing the target ship with the ocean background [1]. It has a unique advantage in tracking the escape of illegal personnel on the sea surface. In order to achieve the goal of reproduction the real ocean color, the color reproduction effect of paints should be evaluated. The color of ocean surface is influenced by many factors, such as the depth of ocean and seabed surface, the chemical composition, the species and density of plants and animals in different sea areas, which lead to the change of ocean color with the distance of coastline [2,3]. The final color of the ocean is the result of selective absorption, reflection and scattering of visible light by sea water and its various substances.

At present, the evaluation of color reproduction is generally based on color matching [4,5]. This evaluation method has been widely used in industries related to color reproduction. It is carried out under the conditions of specific light sources and standard color observers. This evaluation method which is based on human visual matching has the drawback of metamerism. The color evaluation based on spectral matching starts with the essence of material color. The spectral characteristics that are the essential attribute of material are not affected by external conditions, and can realize the reproduction of real ocean color. In this paper, we select three typical ocean spectra including coastal waters, medium seas and high seas. The spectral curve of every sea area is used as the standard to evaluate the color of paints. Then using the color evaluation method combined chroma and spectral accuracy to evaluate the effect of paints reproducing the marine color.

2. The Principles of Color Evaluation

At present, the most widely used color evaluation is color matching based on human vision, which mainly takes into account the subjective feelings of the human vision. The evaluation based on spectral matching is to study the essential properties of material color. It mainly evaluates the similarity from the data of spectral reflectance and its curve shape. In this paper, color evaluation of paints is carried out from two aspects of chroma accuracy and spectral accuracy [6-8]. The chroma accuracy of paints is evaluated by two indicators, which are CIE1976 color difference and brightness contrast. The spectral accuracy of paints is evaluated by three indicators, which are widely used including root mean square error RMSE, good fitting coefficient GFC and Spectral angular distance SAD [9].

2.1. Evaluation Method Based on Chromaticity

The brightness contrast and CIE 1976 color difference formula based on CIE La*b* uniform chroma space are used to evaluate the color reproduction of paints. The Euclidean distance of two colors is used to calculate the color difference in La*b* color space. The specific formulas are as follows:

CIE 1976 color difference:

$$\Delta E = [(\Delta L)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2} \tag{1}$$

Brightness contrast:

$$C = |Y - Y'|/Y' \tag{2}$$

C is the brightness contrast between paints and ocean. Y is the brightness coefficient of paint color and Y' is the brightness coefficient of ocean color. The smaller the color difference and brightness contrast, the closer the two colors are.

The value of Lab in Formula(1) and the value of Y in Formula(2) are calculated by using D65 light source and tristimulus values under 10 degree viewing field. The detailed calculation process is as follows.

$$\begin{cases} X = \int k\varphi(\lambda)\bar{x}d\lambda \\ Y = \int k\varphi(\lambda)\bar{y}d\lambda \\ Z = \int k\varphi(\lambda)\bar{z}d\lambda \end{cases} \tag{3}$$

$$\begin{cases} \varphi(\lambda) = P(\lambda) \\ \qquad or \\ \varphi(\lambda) = R(\lambda)P(\lambda) \end{cases} \tag{4}$$

XYZ represents the tristimulus values of human eyes perception of object color, and the $\varphi(\lambda)$ represents the stimulus of object color. When the observed object is the luminant, $\varphi(\lambda) = P(\lambda)$, $P(\lambda)$ represents the spectral power distribution of the light source; When the observed object is the non-luminant, $\varphi(\lambda) = R(\lambda)P(\lambda)$, $R(\lambda)$ represents the spectral reflectance of the object. $\bar{x}\bar{y}\bar{z}$ represents the tristimulus values of standard observation under the condition of 10 degree viewing field.

$$\begin{cases} L = 116\left(Y/Y_0\right)^{1/3} - 16 & (Y/Y_0 > 0.008856) \\ L = 903.3\left(Y/Y_0\right)^{1/3} & (Y/Y_0 > 0.008856) \\ a = 500\left[f\left(X/X_0\right) - f\left(Y/Y_0\right)\right] & (f(M) = M^{1/3} \ \ M > 0.008856) \\ b = 200\left[f\left(Y/Y_0\right) - f\left(Z/Z_0\right)\right] & (f(M) = 7.787M + \frac{16}{116} \ M < 0.008856) \end{cases} \tag{5}$$

In the Formula(5), $X_0Y_0Z_0$ is the tristimulus values for lighting source D65, X0 = 95.017, Y0 = 100, Z0 = 108.813. M represents the values of X/X_0 , Y/Y_0 and Z/Z_0, respectively.

2.2. Evaluation Method Based on Spectral Accuracy

RMSE, GFC and SAD are the three main evaluation indexes for the evaluation of paints and ocean spectra. The RMSE is expressed by the deviation between the spectral value of paint color and the standard spectral value of ocean. The smaller the deviation, the higher the similarity. SAD refers to the angle between two space vectors. the spectral curves of paint color and the standard spectral curves of ocean are regarded as two space vectors. The smaller the angle is, the higher the similarity between the two curves is [10]. The GFC which is another spectral matching index is established based on Schwartz inequality, which is used to evaluate the accuracy of the two spectral curves. When the value reaches 99%, it is considered that the spectral matching has reached the ideal matching.

Root mean square error:

$$RMSE = [\sum(R - \widetilde{R})^2 / n]^{1/2} \tag{6}$$

Good fitting coefficient:

$$GFC = \frac{|\sum(R.*\widetilde{R})|}{[\sum(R^2)]^{1/2}[\sum(\widetilde{R}^2)]^{1/2}} \tag{7}$$

Spectral angel distance:

$$SAD = \cos^{-1} \frac{|\sum(R.*\widetilde{R})|}{[\sum(R^2)]^{1/2}[\sum(\widetilde{R}^2)]^{1/2}} \tag{8}$$

R and $\widetilde{R}$ represent the spectral reflectance of paint color and ocean color, respectively.

3. Experiment

3.1. Experimental Method

In the experiment, 15 paint blocks were selected as the experimental samples, X-Rite Color-Eye 7000A spectrophotometer was used to measure the spectral reflectance of paint blocks. The experiment was carried out in standard lamphouse under D65 light source . The surface spectra of three typical seas were measured by the advanced spectrometer PoriflerII, which is specially used to measure the spectral reflectance of water surface and underwater. The measured spectra as the standard spectra for evaluating the paint colors. In the range of 400-700 nm at intervals of 10 nm the spectral reflectance data were selected as the experimental data. The evaluation indexes of paint colors and ocean colors were calculated by using D65 light source and tristimulus value under 10 degree viewing field.

Table 1. Numbers of Paints and Sea Areas.

|	Coastal water	Medium sea	High sea
	C1	M1	H1
	C2	M2	H2
	C3	M3	H3
			H4
Paints	C4	M4	H5
	C5		H6
Sea Areas	S1	S2	S3

According to the three standard spectra of ocean, the corresponding numbers of paint blocks are selected as 5, 4 and 6, respectively. The specific numbers are shown in Table 1. Corresponding to the standard spectral curves, the spectral curves of paints are shown in Figure 1-3.
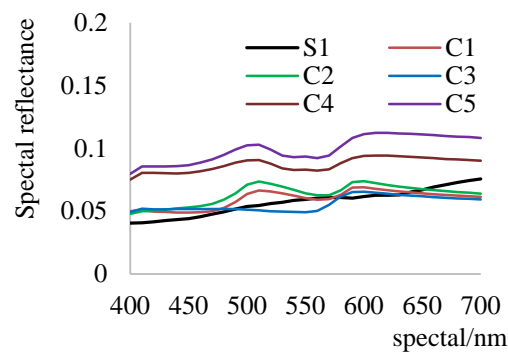
Figure 1. The spectral curves of paints and coastal water.
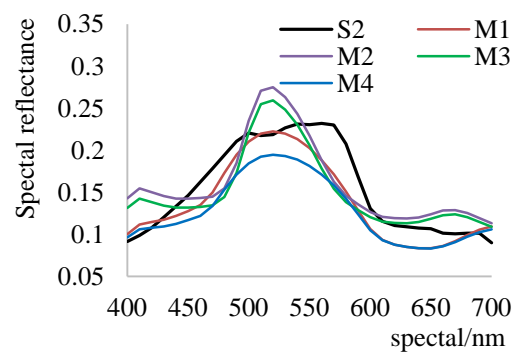
Figure2. The spectral curves of paints and medium sea.
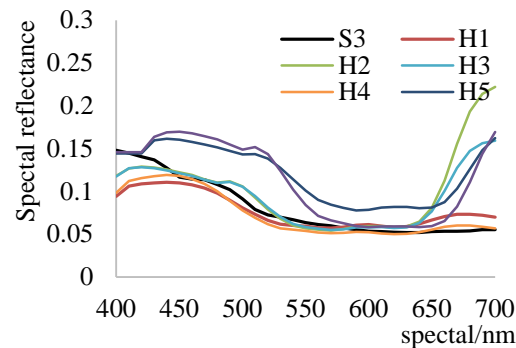
Figure 3. The spectral curves of paints and high sea.

3.2. Results and Discussion

The spectral reflectance data obtained above are used to calculate the chromaticity and spectral accuracy of various paints and ocean standard spectra. From two aspects, the analysis and evaluation were carried out. The evaluation indexes include ΔE and C, RMSE, GFC and SAD. The results are arranged from small to large according to ΔE. The evaluation results are listed in Table 2.

Table 2. Evaluation results of paints and standard ocean spectra.

Numbers of paints	Chroma evaluation		Spectral accuracy evaluation		
	ΔE	C	RMSE	GFC	SAD
H1	1.02928	0.00041	0.01729	0.98293	0.18503
C1	1.17059	0.06155	0.00715	0.99321	0.11666
M1	1.71891	0.03916	0.03354	0.97988	0.20093
H2	1.86045	0.07486	0.05374	0.88372	0.48703
C2	2.43115	0.14146	0.00962	0.99212	0.12561
M2	2.48526	0.09198	0.03259	0.98007	0.19998
H3	2.56113	0.07936	0.03611	0.93679	0.35744
H4	3.18053	0.07562	0.01391	0.99250	0.12253
M3	3.71526	0.13349	0.02440	0.99353	0.11379
M4	5.48829	0.19157	0.04019	0.97712	0.21431
C3	6.30447	0.07216	0.00783	0.99127	0.13222
C4	7.65074	0.47881	0.03066	0.99081	0.13569
H5	7.68826	0.49083	0.0500	0.95611	0.29737
H6	8.43943	0.28017	0.05044	0.94921	0.32007
C5	9.13286	0.68535	0.04252	0.99458	0.10413

Figure 4 shows the distribution of ΔE and GFC of paint blocks and ocean colors. Combined with Table 2, it can be seen from Figure 4 that there is no relative relationship between ΔE and GFC. When the ΔE is small, the spectral GFC may be very high, such as C1, M3 and H4. The spectral GFC may be very low, such as M1, H2 and H3. When the ΔE is large, the spectral GFC of C3 and C5 is very high, while that of H5 and H6 is very low. When the ΔE is small and the spectral GFC is high, there is a small metamerism between paint color and ocean color, which makes it difficult to distinguish the difference between them. However, in the case of small ΔE and low GFC, the ship paints and ocean colors will have serious metamerism phenomenon. Even though it is difficult for human eyes to detect under the same observation conditions, the ships coated with paints can also be identified by measuring instruments.
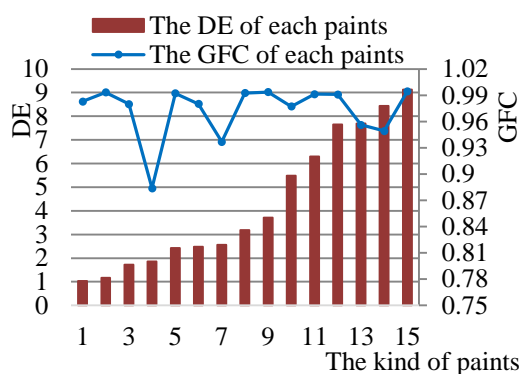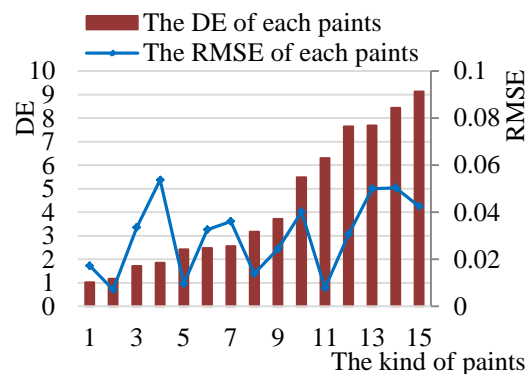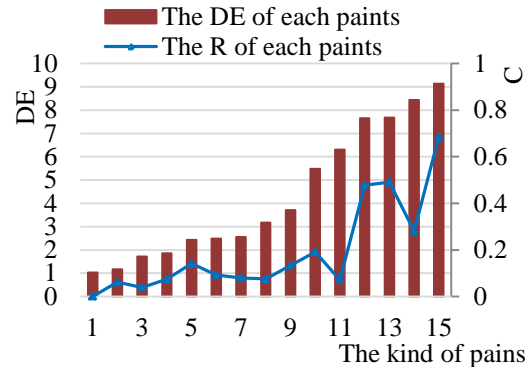

Figure 4. The distribution of ΔE and GFC.   **Figure 5.** The distribution of ΔE and RMSE.

Figure 5 is the distribution of ΔE and RMSE of paint color and ocean color. Figure 6 is the distribution of ΔE and SAD of paint color and ocean color. The spectral angle describes the similarity of the two spectral curves in shape. While the RMSE describes the degree of deviation of the target value from the true value from the spectral data. The smaller the value, the higher the spectral curves similarity. That is to say, the spectral accuracy is higher. It can be seen from the both graphs that the spectral accuracy of paints with small ΔE may be not high. For example, the color difference of H2 is small, the RMSE and the SAD is very high. The color difference of C3 is big, the RMSE and the SAD is small. The spectral accuracy and chroma accuracy are not consistent.
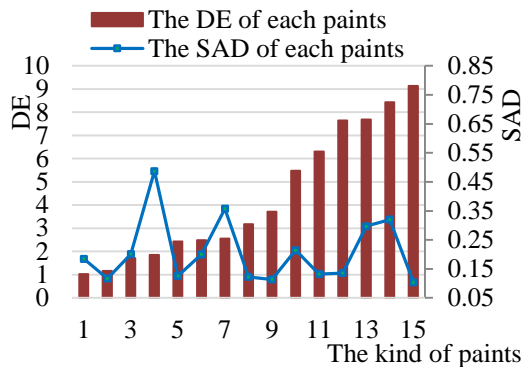
Figure 6. The distribution of ΔE and SAD.　　　**Figure 7.** The distribution of ΔE and C.

　　　As can be seen from Figure 7, there is a positive correlation between brightness contrast and color difference. To some extent, the bigger the brightness contrast C is, the bigger the ΔE is. From the color difference formula and color attributes, the brightness is the main factor affecting the color. Therefore, in order to reduce the color difference ΔE, attention should be paid to reducing the C of two contrast colors.

4. Conclusion

In the paper, the color evaluation of the paints which reproduce the ocean color were carried out. Comparing the chroma and spectral accuracy of the paints and ocean color, it is found that the paint color blocks with small color difference ΔE and brightness contrast C may be not good in GFC, RMSE and SAD. This will lead to serious metamerism phenomenon. Even though the paints color difference ΔE is very small and it is difficult for human eyes to recognize, it is also easily identified by the means of measuring instruments.

　　　Therefore, in order to achieve the goal of reproduction the real ocean color, the spectral accuracy should be improved while reducing the ΔE and C. The combination of chroma evaluation and spectral accuracy evaluation can be used to accurately evaluate the effect of paint reproducing ocean color. This method of evaluation and feedback is of great significance to produce the paints that can truly reproduce the ocean color.

5. Acknowledgments

6. References
[1]　Li Y, Zhu H and Zhang B 2015 Research status and development trend of stealth coatings *J. Material report* **29** (S2): 358-360.
[2]　Wang Y, Ye W, Lao G and Wang K 2014 Analysis of spectrum characteristics of the acquired sea clutter data based on HHT. *Computer Applications and Communications (SCAC), 2014 IEEE Symposium on. IEEE.* p 32-36.
[3]　Dierssen H M, Zimmerman R C and Leathers R A 2003 Ocean color remote sensing of seagrass and bathymetry in the Bahamas Banks by high resolution airborne imagery. *J. Limnology & Oceanography* **48** (1):444-455.
[4]　Li K, Zhao Y and Cui M 2017 Printing color reproduction and evaluation based on image color model *Journal of Qilu University of Technology* **31** (06): 44-47.
[5]　Jiang Z 2014 Research on color deviation detection technology based on Lab space chroma (Xi'an: University of Electronic Science and Technology).
[6]　He S, Chen Q and Duan J 2016 Spectral Prediction Method for Manuscript Primary Colors Based on Constrained Nonnegative Matrix Decomposition *J. Spectroscopy and Spectral Analysis* **36** (10):3274-3279

[7]   Liang D, Zhang L and Li B 2016 Multi spectral image reconstruction based on optimal Wiener estimation *J. packaging engineering* **37**(11):164-170

[8]   Yu H, Liu Z and Zhang L 2014 Effects of Sample Characteristics on Spectral Image Reconstruction *J. packaging engineering* **35**(13): 144—149.

[9]   Li Y, Liu C, Chen H, Chen Q and He S 2018 Spectral prediction method of printing original color ink based on non-negative matrix decomposition *J. Spectroscopy and Spectral Analysis* **38** (12): 3864-3870.

[10]   Sun Y, Zhang X and Shuai T 2015 Radiation normalization of hyperspectral images with spectral angle-Euclidean distance *Journal of Remote Sensing* **19** (04): 618-626.