The color metamerism evaluation of paint based on ocean spectrum

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Abstract. The surface color of the sea is affected by many factors and will be different due to the material difference in the sea. And the difference will be reflected in the ocean spectrum. If the paint materials of a ship can simulate the ocean surface color and the ocean spectrum at the same time. This will minimize the metamerism. In this paper, the method of metamerism is used to evaluate paint based on ocean spectrum, so that the color of the material affected by the light source will be reflected in the metamerism index.

1. Introduction
The surface color of the sea is affected by many factors and will be different due to the material difference in the sea. Sunlight is composed of light of various wavelengths, and different wavelengths of light show different colors [1, 2]. In the dissemination process of the light, the light go through different process, such as scattering, refraction, reflection, etc. In most cases, the surface of the ocean is blue, most of the blue surface of the ocean is due to sunlight resulting from absorption and scattering. Similar to the formation of blue sky, the color of the ocean is more related to absorption. In seawater, the absorption in the red band is stronger and the absorption in the red band is weaker. In addition, aquatic plants and plankton in the oceans also have a strong effect on the color of the surface of the oceans. Due to the different amounts of sediment in the water, the color of the ocean will also be affected. This is also an important reason why the color of the ocean changes with distance from the coastline [3].

In the category of colorimetric, metamerism is an important way to evaluate color and is very useful for color evaluation with different spectral power distributions. The reflectance of an object reflects the most fundamental property of the color of an object's surface. Because the color human finally senses is due to the spectral reflectance of the surface of the object, the spectral power distribution of the light source and the three response curves of the human eye, so the same color may eventually be produced even if the spectral reflectance of the object surface is different. This is a typical metamerism phenomenon [4].

2. The calculation of object metamerism
According to Glassman's law, two kinds of light distributions with different spectral distributions may completely match their color appearances, which is called metamerism. In the industrial field, especially in industries such as printing, painting, color photography and color TV, the phenomenon of metamerism is often encountered, so this is an important issue in color science [5].
Under certain illumination and observation conditions, the color displayed by the non-fluorescent material depends mainly on the photometric properties of the material itself. So when the photometric properties of the two non-fluorescent materials are exactly the same, there is no doubt about the same color under the observation conditions. However, if the photometric properties of the two non-fluorescent materials are not exactly the same, they must likely have the same color appearance under a particular illumination and viewing condition. Therefore, when the color reflectance or spectral transmittance of two color samples are different, and the two color samples whose color appearance can match each other under the specific illumination and observation conditions. This is illustrated in Fig. 1. The two samples are called metamerism color or metamerism pair\(^{[6, 7]}\).

![Image](image_url)

**Figure 1.** The phenomenon of Metamerism

In general, tristimulus values for metamerism colors are equal.

\[
\begin{align*}
X &= \int_{\text{vis}} \varphi_1(\lambda) \bar{x}(\lambda) d\lambda = \int_{\text{vis}} \varphi_2(\lambda) \bar{x}(\lambda) d\lambda \\
Y &= \int_{\text{vis}} \varphi_1(\lambda) \bar{y}(\lambda) d\lambda = \int_{\text{vis}} \varphi_2(\lambda) \bar{y}(\lambda) d\lambda \\
Z &= \int_{\text{vis}} \varphi_1(\lambda) \bar{z}(\lambda) d\lambda = \int_{\text{vis}} \varphi_2(\lambda) \bar{z}(\lambda) d\lambda
\end{align*}
\]

(1) \(\varphi_1(\lambda)\) and \(\varphi_2(\lambda)\) express two different color stimuli. If comparing two illuminants with spectral power distributions of \(P_1(\lambda)\) and \(P_2(\lambda)\) respectively.

\[
\begin{align*}
\varphi_1(\lambda) &= P_1(\lambda) \\
\varphi_2(\lambda) &= P_2(\lambda)
\end{align*}
\]

(4)

If we discuss the color of two reflective objects under the same illumination light source with spectral power distribution \(P(\lambda)\) and assume the spectral radiance coefficients \(\beta_1(\lambda)\) and \(\beta_2(\lambda)\) respectively, the spectral reflectance are \(\rho_1(\lambda)\) and \(\rho_2(\lambda)\) respectively.

\[
\begin{align*}
\varphi_1(\lambda) &= \beta_1(\lambda) P(\lambda) \\
\varphi_2(\lambda) &= \beta_2(\lambda) P(\lambda)
\end{align*}
\]

(5)

If the color of two reflecting objects under two different illumination conditions \(P_1(\lambda)\) and \(P_2(\lambda)\), then

\[
\begin{align*}
\varphi_1(\lambda) &= \beta_1(\lambda) P_1(\lambda) \\
\varphi_2(\lambda) &= \beta_2(\lambda) P_2(\lambda)
\end{align*}
\]

(6)

Metamerism colors are often referred to as two colors that have different luminosity characteristics with the same color appearance under the same lighting and viewing conditions. At this time, if you change the lighting condition or the observer, then the color matching will be destroyed or called mismatch, so CIE international organizations have proposed two methods to evaluate this color mismatch. One method is to change the spectral power distribution of the illumination source, one is to change the observer's matching function\(^{[8]}\).

Metamerism has important applications in the industrial field. In actual production, often need to reproduce a color, it is important to reproduce accurate color. However, losing match is one of the most typical example in the printing and dye color filed, we want to get the same color appearance under a selected lighting condition. But it is very difficult to use exactly the same formula and pigment characteristics in the process of specific color reproduction. Not to mention using the different
materials to copy the color. Therefore, in such a case, the two color samples need to be evaluated for the degree of metamerism\textsuperscript{[9]}.  

2.1. The concept of metamerism

The degree of metamerism caused by the change of the spectral power distribution of the illuminating body is called the metamerism of the illuminant, and can be evaluated by using the illuminant metamerism index recommended by CIE. The specific calculation method is introduced as follows\textsuperscript{[10,11]}.  

2.2. Reference illuminant and test illuminant

In principle, the reference illuminant recommends the CIE standard illuminant D65. If other reference illuminant are selected, the type should be noted.

The test illuminant gives priority to CIE standard illuminant A or F series typical fluorescent lamps. In the F series light source, it is preferred to choose F1, F2 and F3. If other illuminant is selected in the above process, the type should be noted.

2.3. The tristimulus value of metameric pair

At the time of evaluation, the tristimulus values \((X_{t1}, Y_{t1}, Z_{t1})\) and \((X_{t2}, Y_{t2}, Z_{t2})\) of the test sample 1 and the test sample 2 under the reference illuminant are first calculated, and the tristimulus values \((X_{t1}, Y_{t1}, Z_{t1})\) and \((X_{t2}, Y_{t2}, Z_{t2})\) of the test illuminant are calculated. In the calculation, the wavelength interval is selected in principle to be 5 nm and according to the size of the observed field of view can be used CIE1931 or CIE1964 standard chromatic observer spectral tristimulus function.

2.4. Calibration of the tristimulus values

In general, it is very difficult to accurately match the metamerism. The two color samples are often not exactly matched under the reference illuminant, so there may be some slight differences. Therefore, it is necessary to correct the tristimulus values of samples under the the illuminant.

The correction method of tristimulus value usually has two forms of addition correction and multiplication correction. The formula of adding correction is:

\[
\begin{align*}
X'_{t2} &= X_{t2} + \Delta X_r = X_{t2} + (X_{r1} - X_{r2}) \\
Y'_{t2} &= Y_{t2} + \Delta Y_r = Y_{t2} + (Y_{r1} - Y_{r2}) \\
Z'_{t2} &= Z_{t2} + \Delta Z_r = Z_{t2} + (Z_{r1} - Z_{r2})
\end{align*}
\]

The correction formula for multiplicative correction is:

\[
\begin{align*}
X'_{t2} &= X_{t2} \frac{X_{r1}}{X_{r2}} \\
Y'_{t2} &= Y_{t2} \frac{Y_{r1}}{Y_{r2}} \\
Z'_{t2} &= Z_{t2} \frac{Z_{r1}}{Z_{r2}}
\end{align*}
\]

In the above two formulas, \(X'_{t2}, Y'_{t2}, Z'_{t2}\) is the tristimulus value of the corrected test sample 2. In specific applications, you can use the additive correction method or multiplication correction method for correction, it is optional, but some studies have shown that in some cases, the multiplication correction can be get more satisfactory results than the additive correction.

If the color is the same under the reference illuminant, which is \(X_{r1}=X_{r2}, Y_{r1}=Y_{r2}, Z_{r1}=Z_{r2}\) then \(X'_{t2}=X_{t2}, Y'_{t2}=Y_{t2}, Z'_{t2}=Z_{t2}\). So there is no need for calibration at this time.

2.5. Color difference calculation

After obtaining the tristimulus value \((X_{t1}, Y_{t1}, Z_{t1})\) and \((X'_{t2}, Y'_{t2}, Z'_{t2})\) of the metamerism color samples in the test illuminant, the color difference \(\Delta E\) under the test illuminant can be directly measured. When calculating the color difference, the CIELAB color difference formula in the CIE 1976L*a*b* color space is adopted in principle.
CIE international organization stipulates that the color difference is the corresponding metamerism index. Therefore, the illuminant metamerism index $M_{ilm}$ is:

$$M_{ilm} = \Delta E$$

(11)

3. Experiment procedure

The tristimulus value values of ocean surface color are calculated by the spectra of ocean surface spectra. When recovering the color of the ocean, recovering the spectrum as much as possible at the same time. And some test samples will be made, as shown in Figure 2. The samples was observed under the D65 standard light source.

![Figure 2. Some test samples under D65 standard light source](image1)

The spectral reflectance of each test sample was measured using a spectrophotometer, and the measurement environment is shown in Figure 3. The spectral curve comparison of ocean spectrum data with one of the paint samples is shown in Figure 4.

![Figure 3. Sample spectral reflectance measurement environment](image2)
Figure 4. Spectral curve comparison of ocean spectrum and the paint sample

The tristimulus values of the test samples under the D65 light source were calculated and the metamerism indices under the A, F1, F2, and F3 light sources were calculated too. The above calculation results are calculated by software, the basic interface of the software and the results shown in Figure 5. From the software run results, it can be seen that by importing the standard spectral data (ocean spectral data) and the test sample spectral data (the spectral data of the paint material). The CIEXYZ and CIELAB values of the standard sample spectra and the test samples under D65 light source can be calculated respectively, and the curve comparison diagram between the two spectral data is plotted simultaneously. The software will also calculates the color and brightness difference at the same time.

Figure 5. Program running interface

Through the software above, for the paint material which made by simulating the ocean surface spectrum can not only compare the accuracy of the recovered color, but obtain the color difference with the light source changes form the metamerism under four different light. So the color of the material affected by the light source will be reflected in the metamerism index.
4. Conclusion

It will minimize the metamerism if the paint materials can simulate the ocean surface color and the ocean spectrum at the same time. In this paper, the method of metamerism is used to evaluate paint based on ocean spectrum. Through software, inputting the spectral data of the standard sample and the test sample, the two spectral data will be displayed. And the color difference and the photometric difference between the standard sample and the test sample can be obtained at the same time. And by calculating the metamerism index under the fourth light source, so that the color of the material affected by the light source will be reflected in the metamerism index.

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