Measuring and specifying goniochromatic colors

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1. Introduction

Special effect coatings color depends strongly on the illumination and detection geometries, giving them a very appealing appearance. As a consequence, these coatings have become very popular in the automotive industry and in other applications such as cosmetics and security inks. Effect coatings consist of a transparent substrate containing traditional absorption pigments and flake-shaped effect pigments. Its layered structure gives rise to interferences, which are the origin of this special perceived effect [1-3].

To completely characterize the wide color gamut of these coatings under any illuminant and for any illumination/observation geometry, their spectral Bidirectional Reflectance Distribution Function (BRDF) should be measured for a large number of measurement geometries, thus providing all information required to characterize the color shift. However, this type of measurement is not easy to do and can only be done in very well equipped laboratories. Furthermore, the amount of data contained in a spectral BRDF measurement is so huge that getting rapid information from them is not an easy task. However, because of the increasing popularity of these coatings the development of new techniques and instruments to characterize the spectral reflectance and the color as a function of the different irradiation/viewing geometrical configurations [1, 4–12] are urgently requested.

In this communication recent developments regarding data reduction of the spectral BRDF for this kind of coatings, parameters to quantify and improve the visualization of their color travel, and a discussion on a minimum number of measurement geometries will be presented.

2. BRDF data reduction

By using a procedure based on principal components analysis (PCA), the spectral BRDF of special-effect pigment coatings can be expressed as a sum of components, in such a way that spectral and geometrical variables are separated as:

$$f_r(\theta_i,\phi_i,\theta_s,\phi_s,\lambda) = \langle f_r(\theta_i,\phi_i,\theta_s,\phi_s,\lambda)\rangle_\lambda \left[1+\sum_{j=1}^{M} c_j(\theta_i,\phi_i,\theta_s,\phi_s)H_j(\lambda)\right] \quad (1)$$

By the application of the multivariate technique of PCA, a few spectra $H_j(\lambda)$ and their corresponding weighing functions $c_j(\theta_i,\phi_i,\theta_s,\phi_s)$ can be determined so that every spectrum of the BRDF at a given measurement geometry can be expressed as a linear combination of $H_j(\lambda)$. The measurement and representation of the spectral BRDF of the special effect pigment material Colorstream T20-02 WNT Arctic Fire will be discussed in the communication as an example.

3. Parameters to quantify color gamut of special effect coatings

The most important feature of special effect coatings is their strong color shift, which can be characterized by a dense-sampled measurement of their spectral BRDF as mentioned before. However, for many applications a more simple numeric quantity is needed to quantify the color shift. A number of different figures can be used for this purpose [14]:

- Total hue angle variation: the maximum variation in hue angle along the interference line with aspecular angle θ_{asp} = 10º.

- Chroma variation: the maximum variation of chroma along the absorption line with bistatic angle θ_{bi} = 10º.
- Absorption chroma: on the absorption line with bistatic angle θ_{bi} = 10º, it is the chroma at the highest aspecular angle, when scattering from absorption pigment prevails over reflection from interference pigments.
- Contribution from absorption pigments (C_A). From smaller to larger angles, it is the minimum aspecular angle θ_{asp} at which the hue angle is not constant anymore along the length of the absorption line. It describes how large the overall contribution to color is from the scattering due to absorption pigments.

4. Number of measurement geometries

In a recent publication, an alternative angular coordinate system was introduced that is based on a new physical approach to the optics of effect coatings. With these so-called flake-based parameters, one can calculate sets of measurement geometries that from the point of view of optics are expected to yield virtually identical reflection data [15]. Based in this approach, it is possible to completely characterize the spectral BRDF of a sample using a small number of properly selected in-plane geometries [16]. In this communication a subset of nine geometrical configurations defined by pairs (θ_i,θ_s) with only two different θ_i values will be presented. The measurement geometries proposed in this work can be regarded as two aspecular lines with well-separated illumination angles (θ_i). Therefore, future instruments could be designed only for these two illumination angles and for seven viewing angles that are symmetrical with respect to the surface normal of the sample plane. Nonetheless, the most important advantage is that these measurement geometries make it possible to estimate the color for other geometries.

5. Visual representation of the color shift

A representation of the color of special effect coatings based on in-plane geometries was proposed [14], since it has been observed that measurements at out-of-plane geometries do not contribute additional information to the characterization of the color [16]. Both irradiation angles (θ_i) and viewing angles (θ_s) are defined with respect to coating normal, where the projection of the irradiation direction on the sample is the origin of the azimuthal angles (ϕ_i and ϕ_s). Irradiation angles are positive by definition, whereas viewing angles are positive if they are on the same side of the sample surface normal as the irradiation direction and negative otherwise. The representation is a color gamut table where the measurement geometry is given by the rows (θ_i) and the columns (θ_s). Every cell of the table contains a central square with the reproduction of the color in the corresponding geometry. The background of the cell contains the reproduction of the color but keeps the lightness for every geometry constant in order to clearly show the attainable hues. An example of this visual representation will be shown in the communication.

6. Conclusions

The characterization of special effect coatings color requires stating the geometrical variables which directly impact on the variation of the spectral BRDF. A physical approach to the optics of effect coatings suggests that the so-called flake-based parameters (inclination of the interference pigments and incidence angle on them) are better candidates than the spherical coordinates referenced to the coating surface (conventional geometrical variables). The main advantage of using these geometrical variables is that, unlike the polar angles of spherical coordinates referenced to the coating surface, the spectral BRDF is constant as long as their values are kept fixed. Therefore, the characterization of special effect coatings color would have to be based on the selection of measurement geometries with well-distributed values of the flake-based parameters. Using this concept, a set of nine relevant measurement geometries was proposed. These measurement geometries would make it possible to estimate the color for other geometries. Although the importance of the flake-based approach to understand and characterize this kind of coatings was proven, for practical questions the link between flake-based coordinates and the conventional geometrical variables needs to be preserved.

A visual representation for special effect coatings color was proposed in which this link is very apparent. Whereas columns and lines in the representation show color variation with the conventional geometrical variables, diagonals show variations with flake-based parameters. This construction is based in the fact that the aspecular angle (angular deviation of the viewing respect to the specular direction) is closely related with the inclination of the interference pigments and that the bistatic angle (angular deviation of the viewing direction respect to the retro-reflection direction) is closely related to the incident angle on the interference pigments.

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