Appearance Measurements in Industry and their Application in Light Reflection Models

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Abstract

We investigate appearance standards in industry for gloss, haze, and goniochromatic color. Advantages of using appearance standards directly connected to physical reflection parameters include the small number of required measurements and the inexpensive commercially available instruments necessary to acquire the data. We review light reflection models recently developed for metallic and pearlescent colors that are accurate enough for industry applications ranging from interactive to real-time calculation speeds. To solve the real-time constraints, we have chosen to simulate the paint appearance thanks to textures on GPU.

Keywords: color, optics, reflection and shading models, rendering

1 Introduction

How an object looks has been recognized to be important in both the field of computer graphics and the appearance industry. The reaction by computer graphics researchers has been to develop increasingly general models of surface reflection and to build ever reflection measurement devices. This has led to the use of the Bidirectional Reflection Distribution Function (BRDF) to represent reflection and to the measurement of a BRDF by the use of a spectrogoniophotometer. The appearance industry professionals have tried to determine the minimum number of measurements necessary to characterize the largest possible set of practical appearance problems. This has produced one-dimensional scales of appearance, such as gloss, and inexpensive appearance measurement devices, such as glossmeters.

1.1 Goniochromatic Paints

The color of an opaque dielectric is typically modeled with Lambertian reflectance that is the color is considered constant with respect to the viewing angle. However, the goniochromatic materials such as metallic and pearlescent paints change color with viewing angle.

Metallic paints are produced by combining metallic platelets with colored particles. In a dry paint the platelets are oriented near parallel to the surface and therefore most of the light is reflected near the specular direction. The colored particles tint the light through selective absorption resulting in a bright color in the near specular direction falling off to a dark color away from specular. This change in lightness is termed flop also called flip/flop.

Pearlescent paint combines colored particles with a small flakes of mica coated with thin layers of metal oxide which both reflect and transmit incident light. These thin layered platelets cause interference and thus the flop phenomena in pearlescents involves variation in all three coordinates of the color space rather than simply lightness.

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2 Industry Appearance

The quantification of appearance by the paint and coatings industries has resulted in a set of appearance measurement standards: tristimulus colorimetry, gloss and haze. *Tristimulus colorimetry* is essentially a measure of diffuse reflection color (shade color). *Gloss* is a measure of the magnitude of the specular reflection, and *haze* also called glitter captures the width of the specular lobe. Refer to Fig. 1 for demonstration of appearance attributes. Gloss and haze are critical for appearance measurement, of knowing how much light is reflected within just a few degrees of the specular direction. Appearance professionals have learned that in many cases, such as automotive metallic and pearlescent paint, only a few key measurements are necessary. Finally, the measurement of gloss, haze, metallic paint and other standardized appearance parameters can all be accomplished with relatively inexpensive measurement instruments.

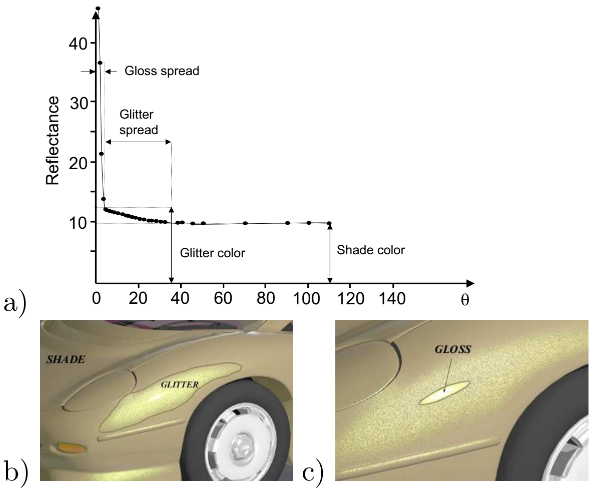

Figure 1: Paint appearance attributes: shade, glitter, and gloss. a) Cross-section of measured BRDF of a pearlescent paint at $\phi = 0°$. The paint views magnified b) 4 and c) 8 times [EvKM04].

3 BRDF Acquisition

Marschner et al. [Mar98] proposed an efficient method to measure the isotropic BRDF of materials. A homogeneous sphere sample of the target material is captured with a digital camera in different lighting conditions. The curved sample surface allows to acquire many BRDF samples at once and yields a short acquisition time. Matusik et al. [WMM03] built an automatic acquisition system and captured a large database of various materials. Ngan et al. [ANM04] analyzed how various analytic BRDF models perform when be used to fit to real measured data. As one result they found that the physically based BRDF model of Cook and Torrance [CT82] performed very well, especially with metal-like materials.

Traditionally, bidirectional distribution functions (BRDFs) are measured by using specially designed devices such as, e.g., gonioreflectometers in a restricted laboratory environment. In order to accelerate the acquisition process, image-based measurement techniques use digital cameras as measurement devices, which due to the large number of pixels in an image allows for acquiring many BRDF samples in a single image. Günther et al. [GCG$^+$05] have built their own high-speed BRDF measurement system, which includes an accurate turn table, a high-quality digital camera, a point-like light source, and a painted sphere as acquisition target. The sphere covered with car paint is mounted on the center of the turn table and captured. During acquisition, the light source moves in increments of 1 degree from the point exactly in front of the camera to the position exactly opposite the camera. Cook-Torrance with multiple lobes is fit to the measured data for efficient BRDF representation.

Figure 2: Rendered sample HDR images of the sphere painted with car paint.

4 Appearance Industry Standards

Gloss is defined by the American Society for Testing and Materials (ASTM) to be the angular selectivity of reflectance, involving surface-reflected light, responsible for the degree to which reflected highlights or images of objects may be seen as superimposed on a surface [52399]. We can differentiate six types of gloss: specular gloss, sheen, contrast gloss (or luster), absence-of-bloom gloss, distinctness of image gloss, and surface-uniformity gloss.

ASTM method D523-39, Test for *Specular Gloss*, measures the light reflected in the specular direction off the sample surface, 60 degrees down from surface normal. A high gloss surface will reflect most light in the specular direction while a surface with low gloss will reflect most of its light in directions other than specular. The numerical gloss value, G, assigned to a surface typically ranges from 100 (high gloss) to 0 (low gloss). An example of low gloss surface is a Lambertian surface. Part of the standard are two more angles, 85 degrees from normal, which measured specular gloss at grazing angles (called sheen) and 20 degrees which measured specular gloss at near normal angles. Results have confirmed that the 20, 60 and 85 degree specular gloss measurements offer numerical values which are roughly linearly correlated over a range of values to perceived gloss of high-gloss, medium gloss, and low-gloss surfaces respectively [52399].

Among other standards that are important to industry are haze and distinctness-of-image gloss measurements specified in

ASTM E430, test method A defines the distinctness-of-image gloss measurements. These measurements compare the light reflected directly in the specular direction to that reflected in the slightly off-specular direction. For distinctness-of-image gloss, the angle of offset is essentially a mere 0.3 degrees off of specular. This is to mimic the keen discrimination the human visual system has for detecting the sharpness of the reflection of an object in a highly reflective surface. The quantity measured is G_{doi}, a larger value of G_{doi} corresponds to a more distinct image.

ASTM E430 offer measurements of the perceived haziness of surfaces. The haze value is a measure of the similarity between the pure specular reflection (measured with 30 degree gloss) and off-specular reflection (measured either 2 or 5 degrees off specular). The notation used for the measured value of haze, H, is an increasing numerical value associated with increasing haziness.

5 Validation of BRDF by Measurements

Westlund and Meyer [WM01] presented a correspondence between BRDF model parameters and standard appearance measurements. A virtual light meter was constructed for this purpose. In the same way that various gloss meters give control over surface reflection properties, a virtual light meter can give control over BRDF model parameters to the computer graphics appearance designer.

The method is essentially a numerical quadrature of the specified BRDF model over an adaptively subdivided source and receptor aperture to compute the final standard appearance value such as specular gloss, haze, and distinctness-of-image. The customizable parameters include the size and locations of the source and receptor apertures, the specular angle, the surface orientation, and the reflection model. This virtual light meter allows the user to determine the specular gloss, distinctness-of-image, haze, etc. produced by a BRDF model with specified parameter values. To find the BRDF model parameters required to achieve a desired appearance value, the program can be run several times using different BRDF parameter values. The ASTM gloss and haze measurements are designed to work with surfaces exhibiting Fresnel effects. Thus, any BRDF model which includes Fresnel reflection can be used without modification in the virtual haze and gloss meter as was done with the Cook-Torrance model.

The problem of the correspondence between the appearance attributes and BRDF parameters have been addressed by Ershov [EvKM04]. As they showed the paint composition parameters can be derived when the appearance of a two-layer paint is known in terms of *shade color*, *gloss spread*, *glitter spread*, and *glitter color*. Figure 3 summarizes the relations describing what appearance attribute relates to which composition parameter for two-layer paints. Some appearance attributes depend on multiple-composition parameters but their corresponding sets of parameters do not overlap, therefore changing one of those appearance attributes does not affect the other attributes.

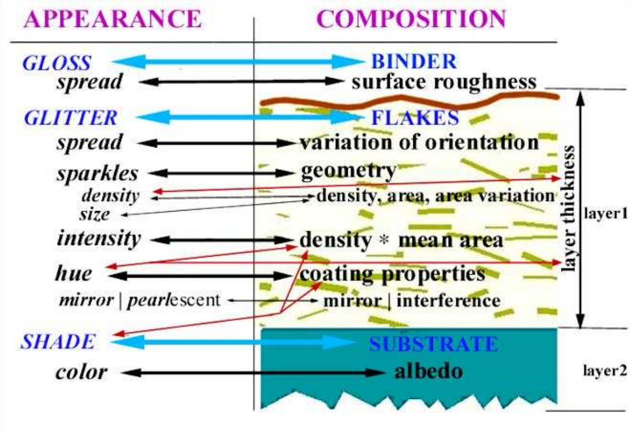

Figure 3: Scheme of appearance based paint design. The scheme demonstrates the approximate relations between the appearance attributes and the composition parameters of a two-layer paint.

6 Color Flop

Measurement of color by a single detector angle is sufficient if there is small angular variation in the objects color this is the case with many scattering pigments. However, a single measurement is not sufficient for goniochromatic materials such as metallic and pearlescent paints where color changes with angle.

Metallic paints have been studied by Saris, et al., he determined that three angular measurements are sufficient for capturing the flop of metallic paints [SGvH90]. The paints were illuminated at 45 degrees from normal and compared instrument measurements to human observation and found the best correlation at measured angles near the specular 25, 45 and far from the specular 110 degrees. Additional discussions and comparisons of various metallic paint measurement methods of metallic paints have been presented by McCamy [McC96].

Although no standards have yet been specified, the measurement angles of existing instruments utilized in industry by Deutsches Institut für Normung (DIN) working group will likely use 25, 45 and 75 degrees even in final specifications for standard measurements of goniochromatic surfaces. The three required angles of measurement have been assigned the names near-specular, face, and flop corresponding to the increasing angles opposite to specular direction.

Pearlescent and other effects paints present more difficulty because of the additional angular dependency of chroma and hue as well as lightness.

Rosler used illumination at four angles from specular but also allowed for surface tilt in three positions to provide a total of twelve aspecular angles [Ros90]. However for more complex interference and effects surfaces, Rosler emphasized that more measurement angles are possibly required.

7 BRDF and Geometry Capture

A virtual surface rendered with an analytical BRDF doesnt have imperfections or variations to be concerned about. Whereas a real surface may have curves or macroscopic height variations, its mathematical counterpart can be assured to be perfectly flat.

The concept of composing a complex shading function from a tree-structured collection of simpler functions and masks was introduced for simulation of Japanese lacquer technique by Ďurikovič [vKE02]. We solved the material separation problem using the measurements directly, before fitting any secondary models to individual BRDFs. This allows for arbitrary blending of materials.

We explore shade trees in a prototype system that begins with densely measured spatially-varying reflectance captured in HDR images, and generates compact shade tree. Original HDR images are separated into the spatial distribution of the component materials according to the reflectance and also the corresponding masks are generated. In addition individual material properties are stored in the spherical maps. A single material is a single stage in the rendering pipeline see Fig. 4.

We prepare samples for each of the types of color used in the item under study. In particular, we make a metallic finish sample where platelets are sprinkled in such a density that no free space between them remains. As a result, the colors of metallic and pigmented finishes mix additively rather than subtractively. This means that if metallic platelets occupy some fraction p of the colored surface, then the BRDF f is a weighted sum of the BRDF of the metallic finish $f_{metallic}$ and those of color pigments:

$$f = pf_{metallic} + \sum_{l} q_l f_l,$$

with p, q_l being positive scalar weights, f_l is the BRDF of the l-th color pigment, and q_l is the fraction of the surface occupied by it. We will consider $f_{metallic}$ as given from measurements and all other basis elements and weight must be estimated. The unknown coefficients can be found by factorization of 3×3 matrix into eigen vectors because we consider only three color pigments. The obtained $p(i,j)$ values are actually the alpha values of the generated texture shown on Figure 4. The second term of equation after linear transformation to the monitor RGB is the RGB residual texture shown also on Figure 4. The alpha component and the RGB image form the final RGBA texture. The input to our system is just a single image of a planar pattern and the $3D$ model where we map the pattern.

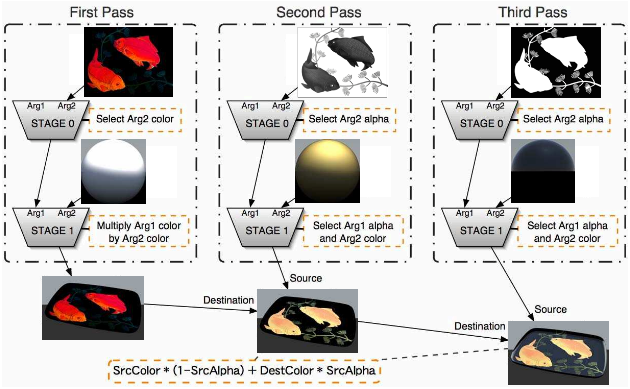

Figure 4: The diagram of rendering passes. The rendering result of the first pass and the output of the second pass are blended using the alpha channel of the second pass. Afterwards, the blended rendering result and the output of the third pass are blended using the alpha channel of the third pass.

The above approach has been used by [LBAD+06] and extended by automatic layer separation for multiple materials. In their approach the sphere map textures were simplified by few BRDF curves and no sphere map texture is stored.

First, they used a spherical gantry with computer control over camera and light source direction to record a set of high-dynamic-range images of planar samples with spatially-varying material under many illumination and view directions. After geometric and photometric calibration, the images are reprojected onto the best-fit plane of the surfaces, yielding a uniform spatial sampling (at approximately 500×500 points) of reflectance measurements.

Secondly, they produce a shade tree with a series of decompositions of the SVBRDF and, using the same algorithms, the component BRDFs. The first level of decomposition separates the SVBRDF into 4D functions that depend on directions of incidence and reflection (the basis BRDFs, as spheres) and 2D functions of spatial position (blending weights). They further reduce the basis materials through a series of decompositions into 2D functions and eventually into 1D curves for interactive rendering or editing.

The representation is more accurate than parametric models, more intuitive than other nonparametric methods, and well-suited for interactive rendering and editing.

8 Conclusions

Standards for measurement of pigment paints have been summarized, unfortunately, the standard measurements for effect paints have as yet been specified. The gloss and haze in the reflection models can be determined using inexpensive measurement instruments. This makes it possible to model the appearance of an existing object by making a few simple measurements. In the majority of appearance applications, the expressive spectrogoniophotometer and the full BRDF are not required. A surface with metallic or pearlescent paints can be rendered using as few as four data values: one gloss measurement in the specular direction and colorimetric measurements in three given directions opposite to specular one.

Also some nonparametric approaches to appearance scanning using multiple textures have been shown. This approach may have difficulties to scan patterns on curved objects and then used them in rendering due to the texture deformations.

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