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Computational Automotive Color Appearance

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Abstract

A computer graphic system has been developed that permits the interactive design of new automotive finishes. The software makes use of a reflection model for car paint that is based on industry standards for measuring the appearance characteristics of the paint. These measurements include gloss for the clearcoat and three aspecular measurements for the metallic basecoat. The program interface provides a means for altering the reflectance properties of the paint and for visualizing the effect of those changes on the color appearance of the car. The desired aspecular measurements for the new paint can be input to a paint formulation system so that the paint can be manufactured. A test of the system shows good correspondence between the designed and the fabricated paint.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism-Color, shading, shadowing, and texture

1. Introduction

The manipulation and specification of color appearance is a critical part of the aesthetic design process. In the creation of a purely artistic object, the manner in which light reflects from the object's surface plays a major role in the impact that the artwork has on a viewer. The patina of a bronze sculpture, the glaze of a ceramic vase, or the color of an oil painting are all important aesthetic components of a piece of art. For the production of a manufactured object (Figure 1), the color appearance can determine whether a consumer reacts positively or negatively to a design. The anodized window mullions of a building, the brushed metal surface of a CD player, or the metal foil packaging of a piece of candy all contribute to a buyer's ultimate satisfaction.

Recent advances in computer graphics hardware have provided aesthetic designers with unprecedented computational control over color appearance. Twenty years ago the development of ray tracing techniques made it possible to accurately simulate both the spatial and the spectral distribution of light reflected from a surface and to produce photorealistic pictures of an object. However, the introduction of per pixel shading hardware within the last five years has allowed *interactive* control over surface reflection properties and has produced image quality equivalent to basic ray tracing. The use of pixel shaders to manipulate the parameters of an arbitrarily complex surface reflection model in real time makes it possible to design new color appearances even if no method is available to have them fabricated.

A true computational aesthetic approach to color appearance design necessitates that there *is* a connection between the interactive design program and the manufacture of actual surface coatings. To be able to produce the artistic object or the commercial product that has been visualized with the computer graphic program requires that there is some known relationship between the parameters of the surface reflection model and, for example, the formula that is used to mix a paint. If this relationship is understood then computer aided color appearance design (CACAD) becomes possible [Mey00].

CACAD is similar to traditional computer aided geometric design in both its intent and in the fact that it was made possible by the introduction of computer graphics (Figure 2). The ability to manipulate wire line objects in real time made it possible to solve geometric design problems that had previously been worked out using pencil and paper. The database for the design produced using computer graphics could be passed directly to numerically controlled milling machines and the final part could be fabricated without requiring intermediate prototypes. While the automotive and aircraft industries have had computer aided geometric design tools for over thirty years, development work in the paint and coatings field is still done entirely by creating physical samples and observing them under controlled lighting con-

Figure 1: *Color appearance plays an important role in many different areas of aesthetic design. One of the most straightforward color appearance design problems involves the selection of a traditional paint for application to the exterior walls of a building or to the interior surfaces of a room. Color appearance plays an important role in fashion design where a material or a fabric may be selected that has complex spatial reflection properties. The production of the accessories that go with a clothing ensemble or the industrial design of consumer products such as dishes and cutlery both require careful attention to the surface finishes that are used and the color appearances that result. The application of makeup to the skin is an aesthetic design problem and cosmetics have complex reflection properties involving scattered light from below the skin's surface. Finally, much thought and effort goes into the coloring of food to achieve uniformity of appearance and to make the food look appetizing (from [HS94]).*

ditions. The emergence of pixel shading hardware will make it possible to use interactive computer graphics to develop and evaluate new color appearance materials without having to produce actual specimens.

2. Reflection Modeling

We have been actively pursuing CACAD of automotive paint for more than ten years. Our efforts in this area began at a time when ray tracing was the only way to accurately simulate complex surface reflection properties. We used this technique to produce our first pictures of metallic paint. We then turned to the appearance industry for guidance concerning the measurement of surface gloss and automotive metallic paint. This led to the development of a reflection model that was based on standard color appearance measurements.

In our earliest attempt to achieve computer aided color appearance design, a model was constructed of the mica chips that lie below the surface of pearlescent paints [GMN94]. The model of these chips included a thin coating of titanium dioxide so that light interference effects that take place on the surface of the chips could be simulated. A virtual goniospectrophotometer was implemented using a ray tracer

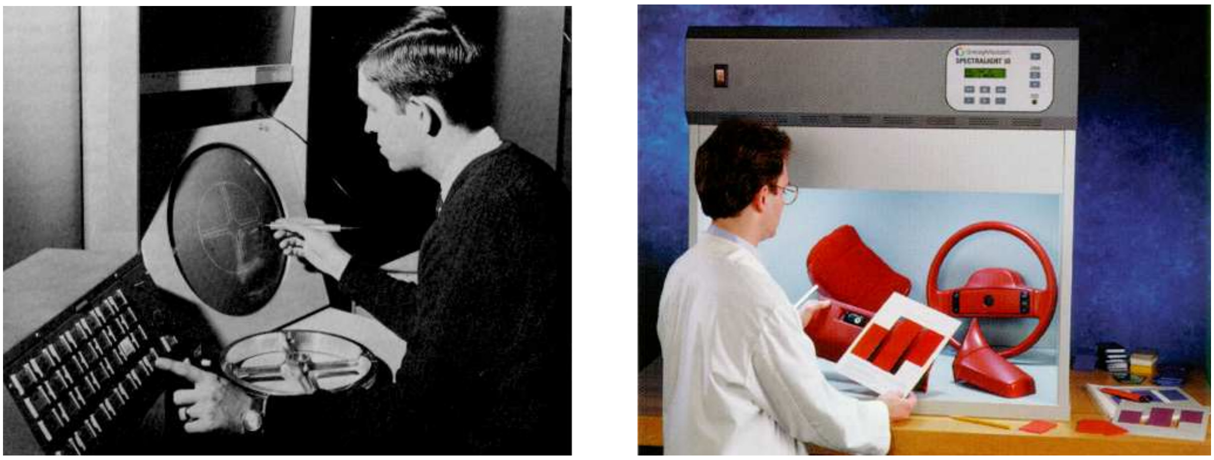

Figure 2: *Simple wireline computer graphics made it possible to design a mechanical part on a CRT, download the description of the part to an automatic milling machine, and have the part fabricated without creating any prototypes (left). This process came to be known as computer aided design. In contrast, the design of new paints and coatings is still done by creating a real physical sample for each variation of the new material (right). This is a time consuming and expensive process that can be eliminated by the use of new computer graphics hardware (from [Pri71]).*

capable of tracking phase shifts in the light traveling along the ray paths. By casting many rays of light at the surface from the same direction, and by using the virtual goniospectrophotometer to record the distribution of the light reflected from the chips below the surface, the shape of the reflection pattern was obtained. At the same time, by keeping track of the phase differences between parallel reflected light rays, light interference effects were simulated. The results obtained with the virtual goniospectrophotometer were subsequently used to synthesize a realistic picture of an object painted with the pearlescent paint (Figure 3).

While it was possible to successfully simulate the appearance of these hypothetical interference paints, it would be impossible to create a real paint with identical reflectance properties. This is due to the fact that the manufacturing process does not allow precise control over the location and orientation of the mica chips. This makes it difficult to connect the modeling and simulation of the paint with the actual manufacture of the paint. A second problem was that a simulation had to be performed using the virtual goniospectrophotometer in order to determine the appearance of the paint. This made it impossible to interactively adjust the appearance properties of the surface coating. For these reasons, this approach to computer aided color appearance design was abandoned.

Our current approach to modeling the surface reflection from automotive paints is based on the standard color appearance measurements that are used in industry. Gloss is a simple measurement based on the ratio of the amount of light reflected near specular to the quantity of light incident on the surface. It provides an indication of the smoothness of the surface and the strength of the first surface reflection. A virtual glossmeter was created to find the correspondence between gloss measurements and the parameters of the Phong and Cook-Torrance reflection models.

Studies within the automotive paint industry have shown that, for metallic automotive finishes, only three color measurements are necessary to capture the second order variation in color with reflection angle for these materials. These three aspecular measurements are taken near the light source direction, near the specular direction, and at a point in between the first two measurements (Figure 4). The complete reflection for the automotive paint is modeled as a linear combination of the first surface reflection (the gloss measurement model) and the metallic reflection (the model based on three aspecular measurements).

3. Interactive Design

Based on the reflection model that was developed for metallic paint, an interactive design program for automotive finishes was created [SMW03]. The interface for this program allows the user to adjust the gloss and to manipulate the three second order curves that determine the color of the aspecular reflection for the paint. As these changes are made, the pixel shader in the program is modified and the result is immediately displayed on the surface of a three dimensional automotive shape (Figure 5). Environment map based lighting is used to show the effect that this change in the surface reflection properties has on the appearance of the paint. A special set of pre-filtered environment maps is linearly combined to allow interactive adjustment of the reflection model parameters [SM05].

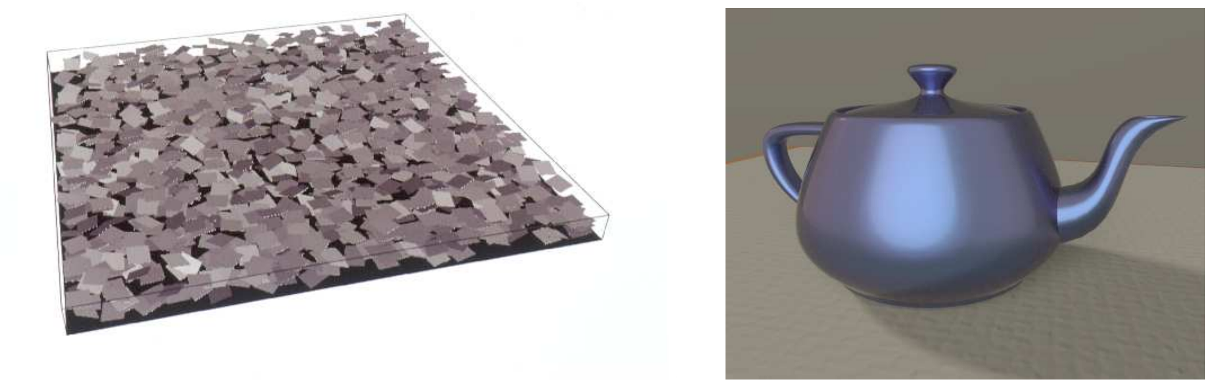

Figure 3: *One approach to the simulation of metallic and pearlescent paints involves the modeling of the subsurface microstructure of the paint (left). A ray tracing system is then used to simulate light interactions with the paint. The results of that simulation are then used to make a computer graphic picture of the paint on the surface of an object (right).*

In addition to directly manipulating the curves, the interface also allows the user to adjust the hue, saturation, and brightness of the paint and to select the face or the flop color of the surface finish. (The face color is the appearance of the paint when viewed perpendicular to the surface, and the flop color is the color seen when observing the surface at a grazing angle.) The program can also output the measurements necessary to fabricate the paint. Recently we conducted a successful one day experiment with the program in which an automotive designer created a new paint, the paint was mixed and sprayed on a surface, and a comparison was made between the designed paint and the actual paint samples [MSE*05].

4. Future Work

There are several ways that we would like to extend our CACAD program for automotive paint so that it takes into account additional variables that affect color appearance. For example the user should be able to manipulate the shape of the object in conjunction with the reflectance to produce a color appearance that "travels" correctly across the surface. This is particularly important for so called "color shifting" colors that have a different color appearance near specular and far away from specular. Contextual elements such as lighting and viewpoint should also be taken into consideration as part of the design, along with surface reflections produced by objects that surround the painted surface. We would also like to develop tools that facilitate particular color appearance design objectives such as insuring that glossy highlights occur at specific positions on the auto body. Finally, by carefully manipulating all of the color appearance variables, it should be possible to optimize the design for the best possible initial showroom impression.

Extending the automotive color appearance design program so that the shape of the object can be modified in addition to the reflectance of the paint that is being applied to the object makes it possible to approach the problem of computer aided color appearance design in two different, but complementary, ways. Given an existing automotive design, the reflectance properties of the surface finish can be tailored to accentuate the best features of the car's shape. This is the approach that is possible using our existing color appearance design program described above. If, in addition, the shape of the object can be adjusted then the sheet metal can be bent to bring out the best properties of the paint. In Figure 6 a superquadric is modified from a cylindrical to a spherical shape. This figure illustrates how shape effects the appearance of a goniochromatic color that takes on a yellow appearance near specular (face color) and a green appearance away from specular (flop color). Lines of constant aspecular reflection are also environment mapped onto the superquadric in Figure 6. This illustrates how a visual reference could be provided to help guide the adjustment of the surface reflection and the deformation of the surface shape.

In addition to the overall shape of an object, there are important local color appearance considerations at the crease in a piece of automotive sheet metal or at the point where two body panels meet. These color appearance problems must be taken into account during the body and paint engineering process or they could become cosmetic flaws in the manufactured car. Figure 7 shows a piece of sheet metal that is being bent in two at an increasing angle and with an enlarging radius between the two halves. The part is painted with a goniochromatic color that shifts from a green face color to a cyan flop color. As the piece of sheet metal begins to bend a significant difference in color is seen between the two halves of the part due to the goniochromatic nature of the paint. This color difference could be seen as a flaw by the consumer if it was located in a highly visible location on the automobile. As the metal part bends further, the radius

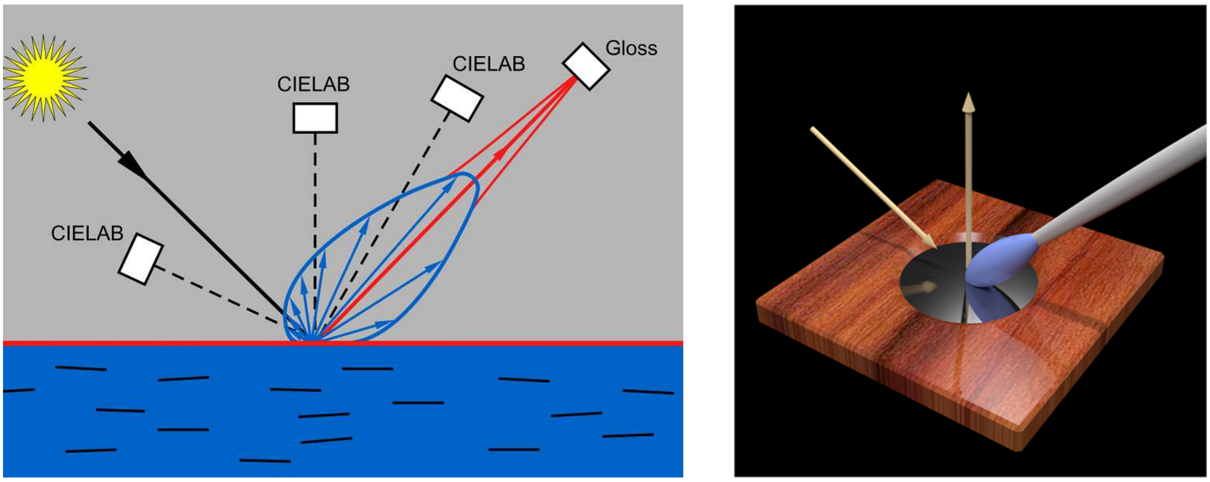

Figure 4: *Light reflection from a metallic paint includes a narrow specular lobe from the clear coat reflection and a broader, but still primarily specular lobe due to the metallic flake reflection. A gloss measurement is used to characterize the clear coat reflection and three aspecular measurements are employed to capture the shape of the metallic flake reflection.*

of the fillet increases. This demonstrates that a potentially undesirable colored highlight could be generated because of the color shifting nature of this particular surface finish.

5. Conclusions

The advent of pixel shading hardware has made it possible to introduce computer aided tools into the aesthetic design of automotive color appearance. We have developed CACAD programs that give aesthetic designers the same control over color appearance that mechanical designers have had over geometry since the introduction of computer graphics over thirty years ago. The CACAD programs that we have written provide both an intuitive interface for adjusting the color appearance and a complex lighting environment for examining the surface reflection as it is modified. These programs can be easily interfaced into the paint manufacturing process by downloading the key parameters that define the characteristics of metallic automotive surface reflection. We have compared the paint samples produced using our program with their appearance on the screen and have found them to be in good correspondence. Possible extensions to the software include the manipulation of shape in addition to surface reflection, and the development of tools to visualize appearance problems that occur at creases in the automotive sheet metal.

References

[GMN94] GONDEK J. S., MEYER G. W., NEWMAN J. G.: Wavelength dependent reflectance functions. In *SIGGRAPH '94: Proceedings of the 21st annual conference on Computer graphics and interactive techniques* (1994), ACM Press, pp. 213–220.

[HS94] HICKS R., SCHULTZ F.: *Product Shots*. RotoVision, London, England, 1994.

[Mey00] MEYER G. W.: Computer aided color appearance design. In *CGIP' 2000: Proceedings of the First International Conference on Color in Graphics and Image Processing* (2000), pp. 195–200.

[MSE*05] MEYER G. W., SHIMIZU C., EGGLY A., FISCHER D., KING J., RODRIGUEZ A.: Computer aided design of automotive finishes. In *Proceedings of AIC Colour 05* (2005), pp. 685–688.

[Pri71] PRINCE M. D.: *Interactive Graphics for Computer-Aided Design*. Addison-Wesley Publishing Co., Reading, MA, 1971.

[SM05] SHIMIZU C., MEYER G. W.: Computer aided color appearance design using environment map based lighting. In *Computational Aesthetics in Graphics, Visualization and Imaging* (2005).

[SMW03] SHIMIZU C., MEYER G. W., WINGARD J. P.: Interactive goniochromatic color design. In *Eleventh Color Imaging Conference* (2003), pp. 16–22.

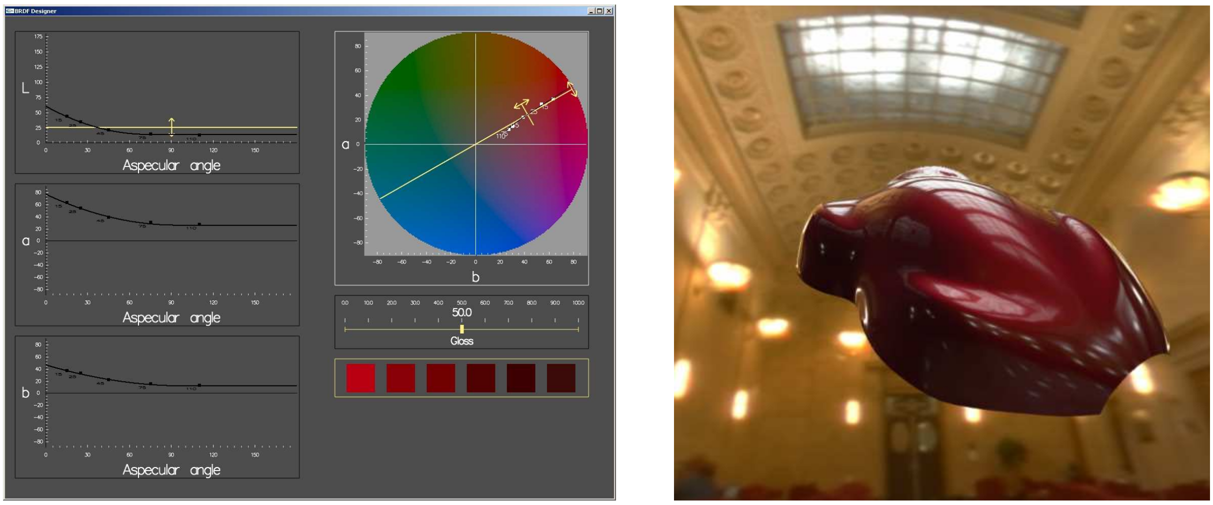

Figure 5: *An interactive design program was developed that allows the user to manipulate the parameters of a metallic paint reflection model. The program has an interface that provides the user with intuitive color controls (left) and permits them to see the appearance of the paint, as it is modified, in a complex lighting environment (right).*

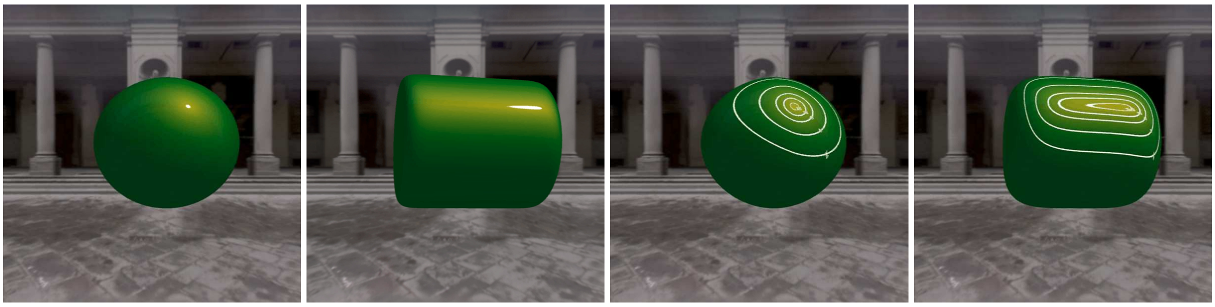

Figure 6: *The shape of an object can be adjusted to show off the properties of the paint to best advantage (left). Contours environment mapped onto the surface show lines of constant aspecular reflection (right). These lines can provide guidance in adjusting the shape of the object.*

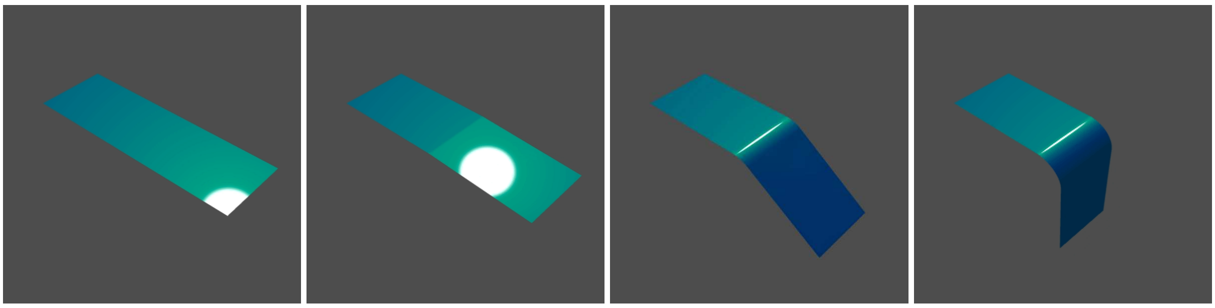

Figure 7: *Bending a sheet of metal illustrates potential color matching problems due to the color shifting nature of the paint. Either the angle or the radius of the bend can produce undesirable color appearance problems.*