Computer Synthesis of Spectroradiometric Images for Color Imaging Systems Analysis

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Abstract

A technique to perform full spectral based color calculations through an extension of OpenGL has been created. This method of color computations is more accurate than the standard RGB model that most computer graphics algorithms utilize. By maintaining full wavelength information in color calculations, it is also possible to interactively simulate and display many important color phenomena such as metamerism and fluorescence. This technique is not limited to creating simple images suitable for interactive display, however. Using this extension, it is also possible to synthesize spectroradiometric images of arbitrary spatial and spectral resolution, for use in color imaging system analysis.

Introduction

Color in the "real world" is a function of many factors, ultimately including the spectral power distribution of the illumination, the spectral properties of the stimulus, and the spectral sensitivities of the observer. Accurate color synthesis for computer graphics needs to account for the full spectral properties of the scene being modeled. Researchers interested in photorealism have known this for years, as spectral information has been used in many global illumination algorithms.[1] Despite this, most interactive graphics routines, and all current hardware acceleration utilize the RGB model for color calculations.[1] In this model, light sources, and surface properties are described by their respective RGB triplets. Color is then determined to be the product of the material properties and the light source. The resulting colors are easy to calculate, but suffer from many problems. One major issue with the standard RGB model is that colors are strongly dependent on the output display device. One set of RGB values might appear quite different across different monitors, as well as across various other media. The RGB model also fails to capture many real-world wavelength interactions that are important for accurate color synthesis. The fundamental basis of this problem is that the color calculations are translated out of the wavelength domain, and into a display domain.[2,3]

Other techniques have been utilized in an attempt to better synthesize accurate color images. The simplest techniques still utilize a tristimulus representation, such as CIEXYZ, HSV, or CIELAB.[2] While these models improve on the strong device dependence of the RGB model, they are still trying to describe full wavelength information with only three values. Various other techniques, such as adaptive integration, Gaussian quadrature sampling, and linear models, more accurately preserve the wavelength information for use in the color calculations.[1,2,4] While these method are far more accurate than the tristimulus based methods, they still rely on simplification of the wavelength information. This simplification inevitably results in a loss of information. This information loss might have no noticeable effect if the final output image is designed for a specific display device. If the desired output image is to contain the full spectral representation itself, any loss of information degrades the entire image.

As color imaging systems become increasingly more complicated, new testing and simulation methods are needed. Obtaining full spectroradiometric image data for imaging system analysis is often a daunting task. Our technique of using computer graphics to create full spectral synthetic images allows for easier color imaging system analysis.

Current Technique

We have extended OpenGL to utilize the spectral properties of materials and light sources to perform color calculations. With the current abundance of OpenGL hardware acceleration, it is possible to maintain interactive performance while achieving more accurate color computations. Using this extension an interactive scene was created, in which the user can alter the spectral properties of the materials or light sources, and see the effects on the resultant colors. This method provides an equal, or more accurate color representation, as previous methods based on a smaller number of basis functions, as it utilizes the full spectral energy distribution. This technique also allows for a great amount of flexibility as well, as the lighting and detectors can be interactively altered, without the need to pre-calculate basis functions.

In this extension, the end-user can specify such material properties as specular and diffuse spectral reflectance, as well as fluorescent excitation and emission spectra. Light sources are also specified by their spectral radiance. The interactions between the lights and materials are then performed while maintaining the wavelength information. Once the spectral properties of the materials and light sources are defined, the total scene radiances are calculated. From there the scene can be rendered using two distinct methods: on-screen simulation, or an off-screen image. Figure 1 shows a flow chart of the procedure used with this technique.

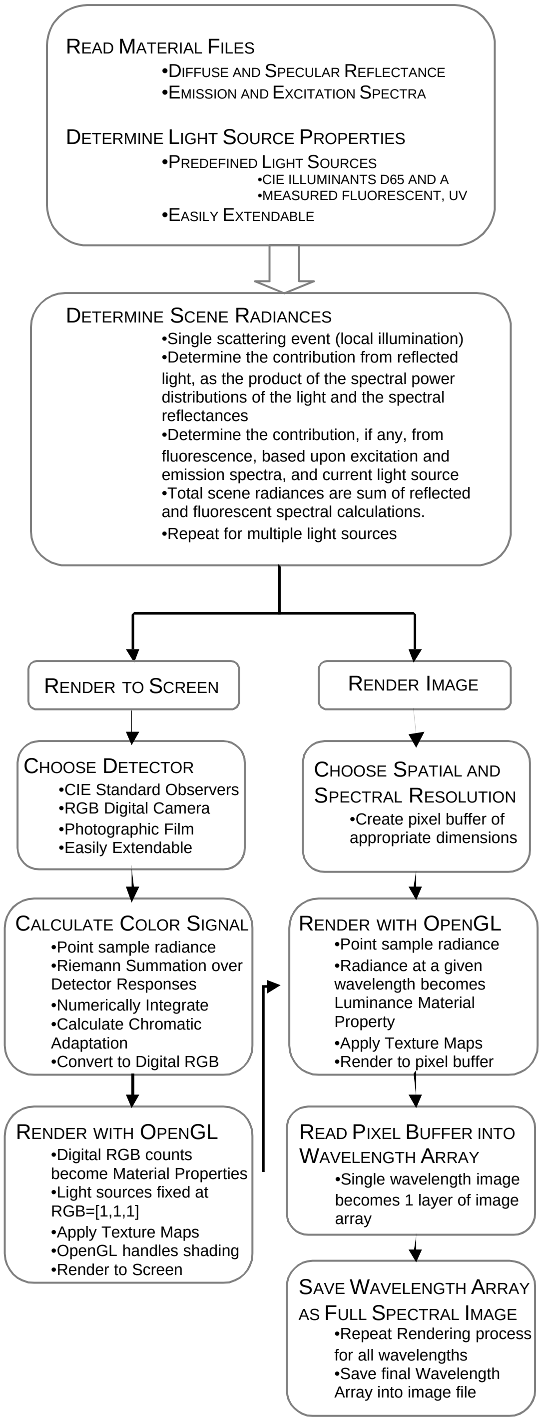

Figure 1. Flow Chart of Spectral Rendering Procedure

If the desired output is a full spectral synthetic image, the scene spectral radiances can be rendered into an image with spectral and spatial resolution limited only by computer memory. This is the "Render Image" path of Figure 1. It is here where this technique excels over previous wavelength based methods. While wavelength selection techniques such as Gaussian quadrature are mathematically elegant and efficient, they rely on simplifying the wavelength spectra into a small number of samples, while maintaining accurate integration. This is acceptable when the spectral information is to be integrated for display, but results in a dramatic loss of wavelength information. Since it is this wavelength information that is desired for full-spectral image synthesis, the wavelength selection techniques are not effective. Linear model techniques are also not effective, as they tend to convert real physical properties into statistical representations.

If the desired output is to be displayed and manipulated interactively, the current technique allows for this as well. The "Render to Screen" path of Figure 1 illustrates how this is accomplished. Since no display is capable of reproducing the full spectral signal, it is necessary to calculate a color signal that can be displayed. This signal is determined after the initial wavelength based color calculations are performed, and is independent of those calculations. The general goal for accurate color image synthesis, is that the resulting signal should be displayed such that it has the same effect on the human visual system as the actual color stimulus would.[3] Our technique is not limited to the human visual system, however. Often it is useful to determine how the colors of a scene would look if photographed either traditionally or digitally, or how the colors might appear to two different people. Once the detector is chosen, the scene radiances are point sampled along with the detector responsivities. Using a Riemann summation technique, the radiances are integrated with the detector response curves. The resulting tristimulus values are then converted to RGB display values. These values are used to set the OpenGL material properties, which in turn are rendered to the screen. Since the light sources have already been accounted for, the OpenGL light sources are set to RGB=[1,1,1]. This allows OpenGL to handle the shading, while the color calculations are handled elsewhere.

Examples

A phenomenon of great importance to the field of color reproduction is that of metamerism. Metameric stimuli are spectrally different stimuli that appear to be a visual match under a given viewing condition. It is the corresponding property of metamerism that forms the basis for any trichromatic color reproduction system. Unfortunately, while the RGB model relies heavily on metamerism for color image synthesis, it is unable to accurately demonstrate this property.

Figure 2 illustrates how the current full spectral extension demonstrates the idea of illuminant metamerism. It is important to remember that while a metameric pair might match under one viewing condition, they might not match if that condition is changed. Using the RGB color model, if two materials visually match under one light source, they must match for all other light sources. The top panel of Figure 2 shows a scene illuminated with CIE Standard Illuminant D65 (average daylight), while the middle panel CIE Standard Illuminant A (incandescent) is used. The bottom panel a measured fluorescent light is used as the simulated light source. The CIE 1931 Standard Observer is used to calculated the display color signal for all the panels. The cows in the scene are defined to have four different diffuse spectral reflectance properties. It can be seen that by changing the spectral information of the lighting the metameric match between the left and right side of each cow breaks down.[5]

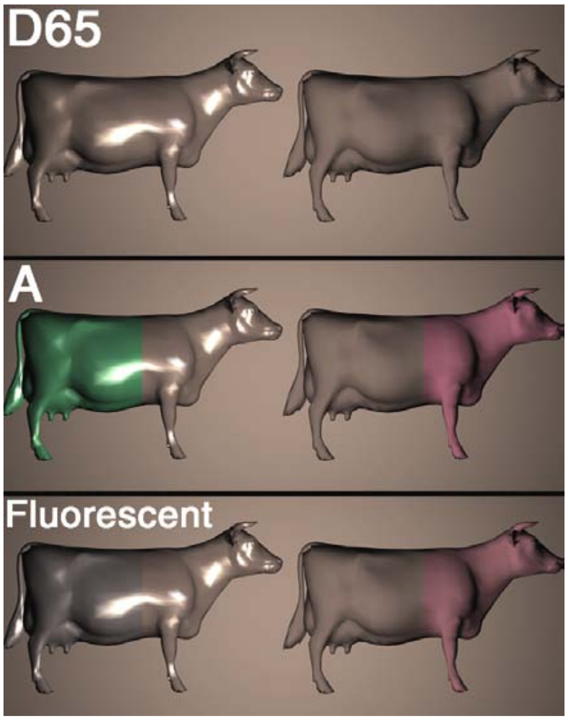

Figure 2. Illuminant Metamerism

Figure 3 illustrates the similar idea of observer metamerism. The top panel in the figure simulates a scene as viewed by the human eye (CIE 1931 Standard Observer), and illuminated by D65. The middle panel shows the same scene and lighting, replacing the color matching functions with the spectral sensitivities of a Kodak DCS200 digital camera with Wratten RGB separation filters. The bottom panel shows the scene simulated as viewed by a generic photographic transparency film.[6]

Another important property that can be demonstrated using full spectral information is that of fluorescence. A fluorescent material absorbs energy (is excited by energy) in one wavelength region, and re-emits this energy in a higher wavelength region. Figure 4 illustrates this property, as the object on the left side is not fluorescent, while the object on the right side is fluorescent. The top panel shows two objects illuminated by CIE Illuminant A, which has very little energy in the short wavelength region, where the fluorescent object's excitation region is. The middle panel shows the two objects under CIE Illuminant D65, which has moderate energy in the short wavelength region. The bottom panel shows the objects illuminated by a UV (black) light, which has most of its energy in the short wavelengths, and little energy in the higher wavelengths.

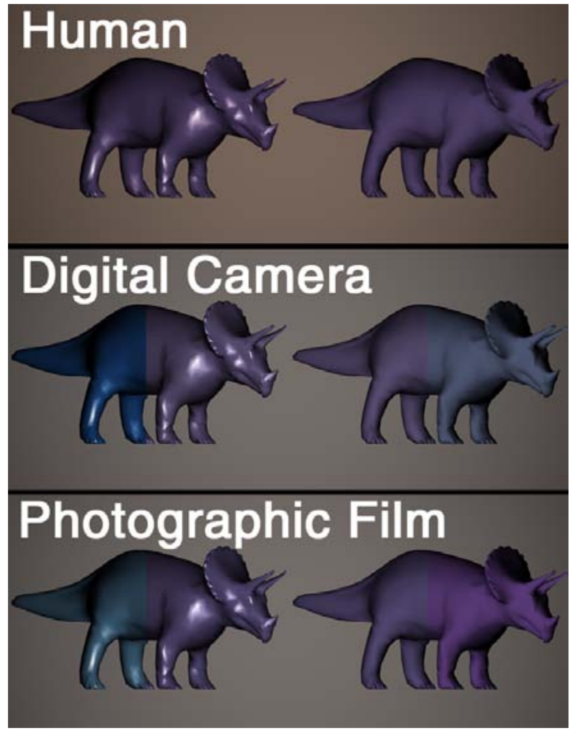

Figure 3. Observer Metamerism

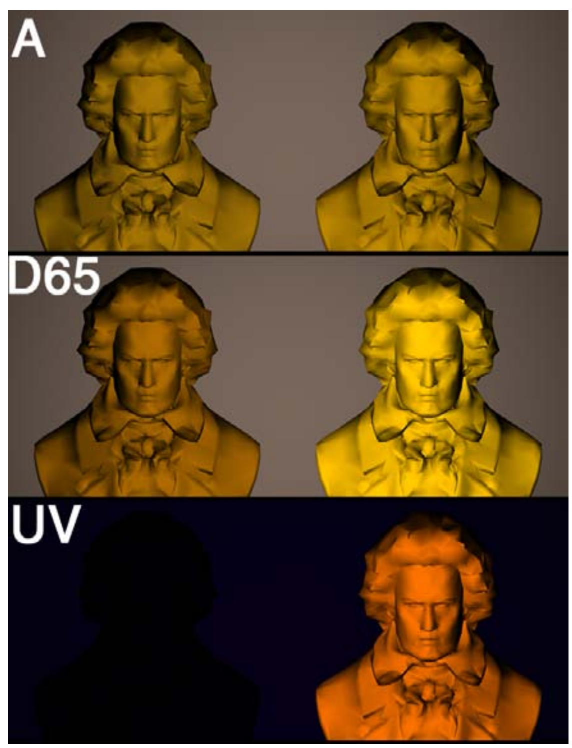

Figure 4. Fluorescence

This extension also allows for the use of full-spectral texture maps. Since any full spectral image is difficult to obtain, it is possible to use the software itself as a method for creating the texture maps. Figure 5 illustrates a more complicated scene demonstrating many different wavelength based phenomena. The picture in the figure is an example of a spectral texture map. This was created using a multi-pass technique, where the scene was fully rendered into an image buffer, and then re-rendered using the image buffer as a texture map.

Although not demonstrated in these examples, the system is also capable of incorporating various levels of gloss, as well as spectral characteristics of gloss (e.g., metallic surfaces). The psychophysical effects of chromatic adaptation can also be simulated for chromatic light sources.

Conclusion

As spectral information has become increasingly necessary for accurate color reproduction, a technique to aid in the analysis of color imaging systems is needed. Computer graphics techniques seem ideally suited for this task. Unfortunately, most interactive computer graphics applications rely on the error prone RGB model for image synthesis. With this in mind, a technique to perform full spectral based color calculations through an extension of OpenGL has been created. With this extension, it is possible to create spectroradiometric images of arbitrary spatial and spectral resolution. It is also possible to interactively simulate many imaging systems, including the human visual system.

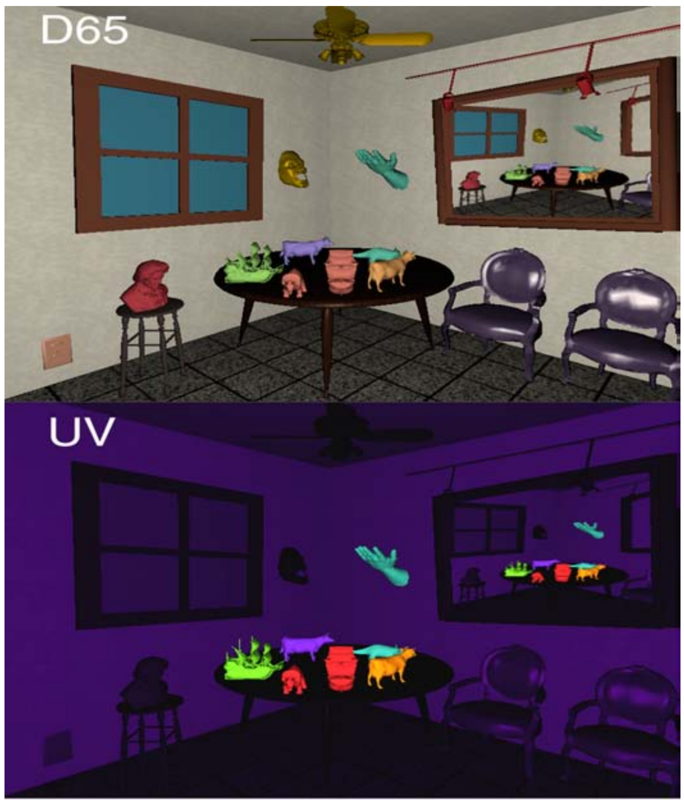

Figure 5. Full Spectral Texture Mapping

The source code and all the spectral data sets are freely available on the World Wide Web.

<http://www.cis.rit.edu/research/mcsl/render.html>

References

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