A Realistic Illumination Model for Stained Glass Rendering

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Abstract. In this paper we present an illumination model for rendering realistic stained glass which simulates the phenomenon of stained glass in real world. The optics for stained glass involves three basic physical mechanisms: diffuse light and specular highlight, Fresnel refraction, volume absorption; these dominate the appearance of stained glass. In this paper, we combine them to render realistic stained glass. Our approach avoids performing any expensive geometric tests, and involves no pre-computation; both of which are common features in previous work. The rendered stained glass images achieve excellent realism.

Keywords: stained glass, Fresnel refraction, light absorption, real-time rendering.

1 Introduction

Like all major art forms, stained glass has offered insights into the aesthetic sensibilities of cultures over time [4]. It usually sets into windows and the purpose of stained glass is not to allow those within a building to see out or even primarily to admit light but rather to control it. For this reason, stained glass windows have been described as 'illuminated wall decorations'. Effects of stained glass change along with illumination conditions. For example, appearances of stained glass are different in the morning or in the afternoon and also changes by the eye position. The photograph of stained glass in Fig. 1 illustrates different brightness of each piece of stained glass according to the view position. In computer graphics, despite the importance of illumination elements, stained glass rendering has not previously been treated realistically and a simple approximation with no luminous light component has been used.

In this paper, we propose an illumination model for rendering realistic stained glass. Generally speaking, the generation of stained glass involves three basic physical mechanisms: diffuse light and highlight, Fresnel refraction, and volume absorption. Diffuse light and highlight contribute to the brightness of stained glass which is typically white and changes along with the light source and the view position. Fresnel refraction dominates the amount of refracted (transmitted) light. Finally, volum absorption occurs in all stained glass and it is particularly important for the color of stained glass. So the rendered stained glass images achieve excellent realism.

We support fully dynamic lighting and viewing direction since there is no pre-computation involved. Our algorithm also runs entirely on the graphics hardware with no computation performed on the CPU. This is an important criterion in certain

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applications, such as games, in which the CPU is already extensively scheduled for various tasks other than graphics.

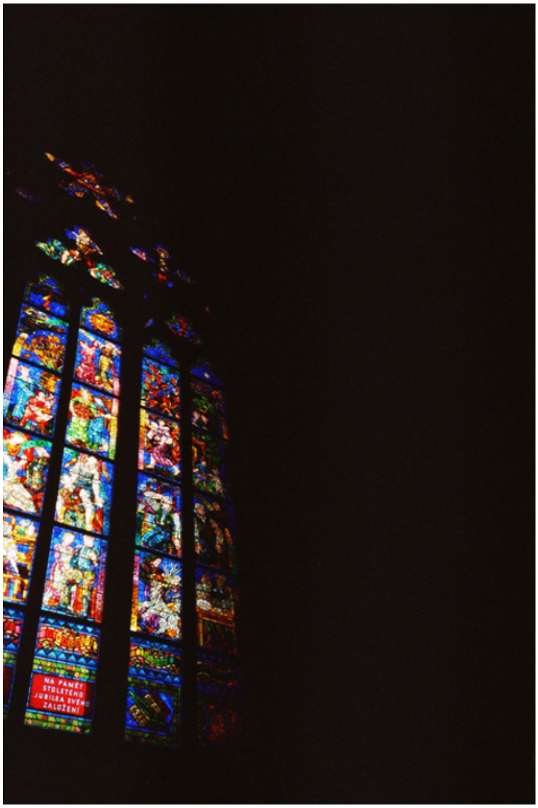


Fig. 1. Stained glass in Prazsky Hrad St. Vitus cathedral. The brightness of each piece of stained glass is difference in the eye position.

2 Related Works

Although stained glass has been subjected to a fair amount of research, a practical real-time stained glass rendering with an illumination model has not existed. In this section, we look at some of the earlier work in stained glass rendering and describe a few cases with particular relevance to our work.

A technique based on Voronoi regions [13] has been used in Photoshop [12]. The simplicity of this method makes it attractive, but in filter, the original image begins to reemerge as the tile size becomes small and in this case the filtered image resembles a mosaic much more than it does in a stained glass window. Recent pioneering works on image-based stained glass presented by Stephen Brooks [4] and a stained glass image filter proposed by Mould [3] achieved high degree in term of stained glass color but do not consider the illumination elements, so the results produced remain different from the appearance of real stained glass and do not support real-time rendering.

The work on rendering diamonds written by Sun et al. [1] resembles our work closely. In this work, they unify Fresnel reflection, volume absorption and light dispersion to render the diamonds. We adopted volume absorption technique [2] and conceived main idea in this work.

Although separate models have been developed for rendering a refraction model [11], volume absorption [2], there has not been a model which unify them for rendering stained glass. In this paper, we combine these phenomena with diffuse light and specular highlight to render the realistic stained glass.

3 Algorithm

The purpose of stained glass is primarily to see the fascinating colors and such effect is generated by the light which comes from outside. In this part we propose three step algorithm for rendering 'illuminated wall decoration' - stained glass. First, diffuse light and highlight contribute to the brightness of stained glass which are typically white and change along with the light source and the view position. Next, Fresnel refraction dominates the amount of transmitted light. Finally, volume absorption occurs in all stained glass which is particularly important for the color of stained glass.

We support fully dynamic lighting and viewing direction since there is no precomputation involved

3.1 Diffuse Light and Specular Highlight

If illuminating light comes from behind stained glass, there are not only diffuse light, but also highlight on stained glass. As you see in Fig. 2, light comes with different

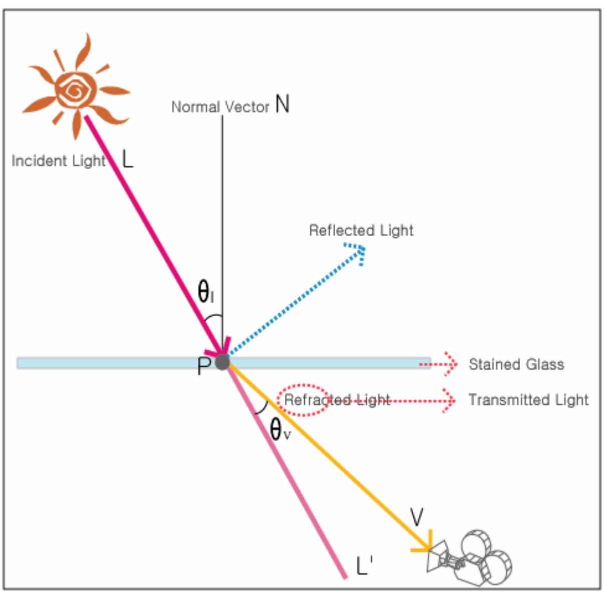


Fig. 2. Transmitted light is changing along with the angle between the light source and the eye position

angle according to the position of the light source. The amount of light entering into the stained glass surface is determined by incident angle θ_l between direction vectors of the normal and the light source. It corresponds to the diffuse component of light shading in conventional computer graphics. According to Eq.(1) we can calculate diffuse color $\boldsymbol{C_d}$.

$$C_d = C_g(L \bullet N) \tag{1}$$

Here, $\boldsymbol{C_g}$ indicates the color of the stained glass. L and N are the direction vector to the light source and the normal vector of the stained glass surface.

Highlight is another important factor for the amount of light. As you see in Fig. 2, when θ_v is equal to 0°, highlight is the brightest and gradually become less as θ_v increases. We can calculate highlight color $\boldsymbol{C_h}$ using Eq.(2)

$$C_h = C_g(V \bullet L')^n \tag{2}$$

where $\boldsymbol{C_g}$ is the color of the stained glass, $\boldsymbol{V}$ and L' are the vector to the eye and the vector of transmitted light which is equal to the incident light vector L. n adjusts the intensity of highlight in the equation. As a result we can calculate the total light $\boldsymbol{C_l}$ by adding $\boldsymbol{C_d}$ and $\boldsymbol{C_h}$.

3.2 Fresnel Refraction

When light wave reaches the boundary of stained glass, some will be reflected and the other will refract (transmitted) at the boundary. The refraction ratio (the ratio of the refractive energy to the incident energy) depends on not only on the angle of incidence and the properties of the material, but also on the polarization of the incident light wave. According to Fresnel formulas [6] [7],

$$\begin{cases} R_{\|} = \left(\dfrac{n_2\cos\theta_i - n_1\cos\theta_t}{n2\cos\theta_i + n_1\cos\theta_t}\right) = \dfrac{\tan^2(\theta_i-\theta_t)}{\tan^2(\theta_i+\theta_t)} \\ R_{\perp} = \left(\dfrac{n_1\cos\theta_i - n2\cos\theta_t}{n_1\cos\theta_i + n2\cos\theta_t}\right) = \dfrac{\sin^2(\theta_i-\theta_t)}{\sin^2(\theta_i+\theta_t)} \end{cases} \tag{3}$$

where $R_{||}$ and $R_{\perp}$ (called Fresnel coefficients) correspond to polarizations that are parallel with and perpendicular to the incident plane. n_1 and n_2 are the refractive indices of the media on the incident and transmission sides, and θ_i and θ_t are angle of incidence and transmission. We approximate the Fresnel coefficient by the average of $R_{||}$ and $R_{\perp}$ which determine the amount of reflection. This approximation is widely applicable because polarization is not important in most practical scenes [10]. We adopt this approximation in this paper. Since the transmitted light is obtained by subtracting the reflected light from total light, we can compute the resulting color as follows.

$$C_r = \left[1 - \frac{1}{2}(R_{\|} + R_{\perp})\right] * C_l \tag{4}$$

3.3 Volume Absorption

Each piece of glass on stained glass has different light absorption capacity. In particular, black edges of stained glass can not transmit light because they are made of wax denture. In addition, volume absorption [2] influences the appearance of stained glass.

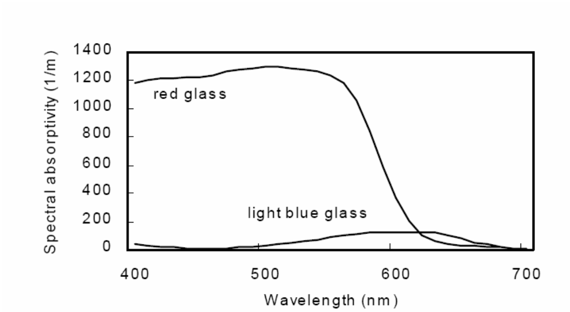
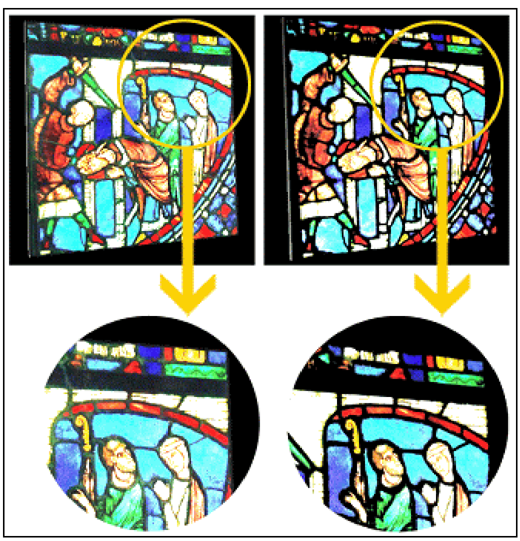


Fig. 3. Examples of spectral absorptivities

Figure 3 shows two typical spectral absorptivity curves: the curve for "light blue glass" is fairly smooth, while the one for "red glass" has an abrupt change. This can cause significant difference in the appearance of stained glass pieces made of "light blue glass" and "red glass."



(a) (b)

Fig. 4. (a) The result without applying light absorption. (b) The result after applying light absorption.

According to the Bouguer-Lambertian law [5] [9] [14], the internal transmittance for light traveling from one point to another inside a transparent material is given by

$$T_{internal}\left(\lambda_i\right) = 10^{-a(\lambda_i)l}, \ i = 1, \ldots\ldots, N \tag{5}$$

where $\alpha(\lambda_i)$ is the material's absorptivity, λ_i is light wavelength, and l is the length of the light path.

According to this law, increasing l decreases the intensity and deepens color saturation of light. Thus, the resulting attenuated color can be obtained as follows.

$$C_{final} = C_r * T_{internal} \tag{6}$$

By combing Eq.(1), (2), (4), (6), the whole procedure can be represented by the following equation.

$$C_{final} = (C_d + C_h) * [1 - \frac{1}{2}(R_{\parallel} + R_{\perp})] * T_{internal} \tag{7}$$

Fig. 5. Result image. Top row: the rendering results with various directions to the eye. Bottom row: the rendering results with various directions to the light source.

4 Results

The stained glass rendering algorithm was developed and implemented on a PC with a Pentium IV 3GHz CPU, 1GB memory and a nVIDIA GeForce 8800 graphics card. The algorithm was implemented using Microsoft DirectX 9.0 SDK and shader model 3.0. We calculate each pixel's direction of light and angle of gaze by using pixel shader. Thus, illumination can be calculated per pixel, including the amount of absorption depending on the wavelength.

The results of the proposed algorithm are shown in Fig.5. For this example, our algorithm can render at about 1400 frames per second with the resolution of 640x480.

Fig. 6. A selection of real stained glass and caustic phenomena

5 Conclusion and Future Work

We have combined the physical mechanisms for rendering realistic stained glass, including diffuse light, highlight, Fresnel refraction, and volume absorption. This work not only improves the capability of achieving excellent realism in rendering stained glass, but also provides fully dynamic lighting and viewing direction.

In real life, because of the participating media such as dusts and vapors in atmosphere, we can see the light rays directly which are transmitted from stained glass. We would like to add this phenomenon to our stained glass rendering algorithm, which might considerably improve the overall appearance of stained glass.

As another future work, we want to apply this algorithm to the field of nonphotorealistic rendering(NPR) of stained glass. Through this way we can produce more realistic images than before in the field of stained glass NPR. Next, in manufacturing stage of stained glass, bubbles and impurities might be contained in stained glass. They may generate spots and light dispersion on stained glass. This phenomenon could enhance the realism of stained glass rendering.

Finally, we plan to include caustic effect generated by light cast through stained glass such as Fig.6.

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