Hidden Watermark of 3D Models by Just Noticeable Color Difference

Tzung-Han Lin, National Taiwan University of Science and Technology, Taipei, Taiwan

Abstract

A watermark is a subtle pattern on images or documents to prevent counterfeiting. For color 3D models, it is feasible for add watermarks on either texture images or vertex colors, as well. We propose a hidden watermark method by superimposing a just noticeable difference pattern on 3D color models. The color difference on the watermark is too small to be noticed and it will be enlarged under specific lighting conditions in the computer graphics environment. This idea is very similar to the anti-counterfeit label on most banknotes. Thus, the watermark is almost invisible when rendering under formal white lights, but visible under violet lights.

Introduction

Nowadays, generating a quality digital 3D model becomes a simple task. So far, there are several methods, such as 3D software and 3D scanners, that are able to assist users to readily create digital 3D models. Recently, 3D scanning devices are getting popular and widely used in various applications. They are able to duplicate 3D complex objects efficiently based on either depth sensors [1] or mobile phones [2]. Besides, traditional 3D graphics software is also a powerful tool to generate 3D models. With the massive increase of digital creations, the counterfeiting issue becomes important.

2D watermarking is a technology of counterfeiting to add a subtle pattern on images based on Fourier transform or similar methods. In 3D watermarking, the technique is usually to hide information in frequency domain which is converted from 3D geometrical shapes [3]. Different from previous works, our method dedicates to hide information based on the visual perception, particularly in color difference. It involves psychophysical topics. We focus on the color appearance of 3D digital model in the computer graphics environment, and we hide the pattern by shifting the color within an ellipse of just noticeable difference (JND). Then, by adjusting the gain values of the lighting, it is likely to enlarge the color difference to be noticeable.

Background

Recently, 3D marketplace becomes an important platform for providing and sharing 3D digital models. Most of them are created by individuals. Based on the infrastructure of 3D marketplace, the spread of data is getting fast. It induces the copyright issue. To prevent counterfeiting, the watermarking therefore becomes one of the potential solutions. So far, few researches works dedicate to imprint a watermark on 3D object by the color difference, particularly for digital 3D models. Our proposed method mainly focuses on imprinting a hidden pattern for anti-counterfeit.

Our objective is to slightly shift the color values of the watermark region on a digital 3D model which has no perceptional difference under uniform white lights. And, the rendering appearance of the shifted colors will look noticeable under a specific lighting color. It is a topic regarding human color

perception and the distance between two colors, which has been addressed in [4]. It also involves the lighting and shading models in computer graphics. The schematic draw is shown in Figure 1.
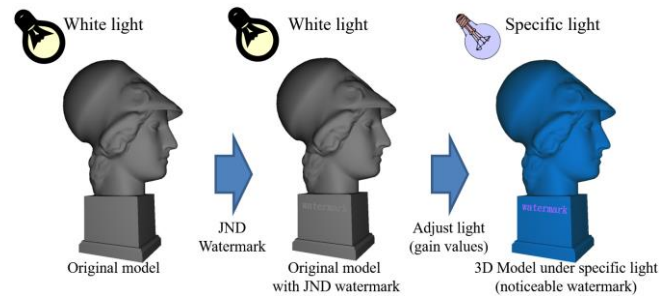

Figure 1. Schematic draw of proposed JND watermark

To carry out this phenomenon, we simplify the shading method and take only ambient and diffusion properties of lights into account. Regarding material properties, it is sometimes various due to the definition of 3D file formats. Conventional 3D file formats, such as OBJ (wavefront) and WRL (vrml), provide extra images for surface texture. PLY, Stanford polygon file format individually provides the color slot for each vertex. It is usually convenient for implement the vertex rendering algorithm, and is widely used in 3D scanning field. In both types of 3D file formats, for our method, they are available for hiding watermarks.

Proposed Method

Color difference

To obtain the color difference, we link the color transformation and computer graphics shading methods. Color difference is a quantity value regarding human perception. Usually, color 3D model already has $[R, G, B]^T$ values either in texture image format or in vertex coloring format. The nominal $[R, G, B]^T$ values are converted by gamma correction into $[r, g, b]^T$, and then be converted into CIE XYZ tristimulus values under a known lighting condition. For example, under standard $D65$ lighting, the conversion will be described as equations (1) and (2).

$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix}^{\gamma}_{nominal} \tag{1}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124564 & 0.3575761 & 0.1804375 \\ 0.2126729 & 0.7151522 & 0.0721750 \\ 0.0193339 & 0.1191920 & 0.9503041 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}_{D65} \tag{2}$$

Based on the reference white $[X_r, Y_r, Z_r]^T$, the tristimulus values are transformed again into CIE $[L, a, b]^T$ by equation (3)~(5). Once the $[L, a, b]^T$ value is obtained, the difference, ΔE^*_{ab}, between to colors is defined as the Euclidean distance as equation (6).

$$\begin{bmatrix} x_r \\ y_r \\ z_r \end{bmatrix} = \begin{bmatrix} X/X_r \\ Y/Y_r \\ Z/Z_r \end{bmatrix} \tag{3}$$

$$f_x = \begin{cases} \sqrt[3]{x_r} & x_r > \varepsilon \\ \dfrac{\kappa x_r + 16}{116} & x_r \le \varepsilon \end{cases}$$

$$f_y = \begin{cases} \sqrt[3]{y_r} & y_r > \varepsilon \\ \dfrac{\kappa y_r + 16}{116} & y_r \le \varepsilon \end{cases} \tag{4}$$

$$f_z = \begin{cases} \sqrt[3]{z_r} & z_r > \varepsilon \\ \dfrac{\kappa z_r + 16}{116} & z_r \le \varepsilon \end{cases}$$

, where κ=903.3, and ε=0.008856.

$$\begin{bmatrix} L \\ a \\ b \end{bmatrix} = \begin{bmatrix} 116f_y - 16 \\ 500(f_x - f_y) \\ 200(f_y - f_z) \end{bmatrix} \tag{5}$$

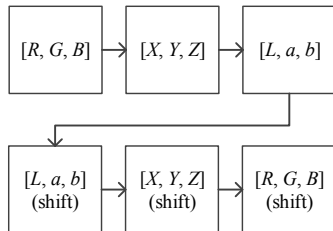$$\Delta E^*_{ab} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \tag{6}$$

Figure 2. Flowchart for generating JND color pattern

A value of "2.3" ΔE^*_{ab} in CIELAB (CIE2000) color space is so-called just noticeable. For every color in 24 bit, its JND is the shell on a sphere in CIELAB domain. To generate a hidden watermark in a 3D model, a vector with JND length in CIELAB domain is applied in desired pixels. Thus, the watermarked pixels are carried out by the flowchart in Figure 2.

We carefully test all color values and statistically estimate all maximum gradients of them under a given illuminated color I_{DI}'. All of the JND shifted vectors are stored as a look-up table (LUT). According to the LUT, we simply shifted the colors of the region where the watermark is. Then, the modified model consists of a JDN watermark.

Shading in computer graphics
We have developed a 3D interface in software for assisting with casting a pattern. Once the cast region of the pattern, which indicates where the watermark is, is determined, we crop the color on the region for processing as a watermark. The colors of the watermark are initially given, and each of the colors is shifted by a JND vector from a LUT.

$$I_{ORG} = K_A I_A + \sum_i [K_D (N \cdot L_i) I_{Di}] \tag{7}$$

$$I_{JND} = K_A' I_A + \sum_i [K_D'(N \cdot L_i) I_{Di}] \tag{8}$$

$$I_W = K_A' I_A' + \sum_i [K_D'(N \cdot L_i) I_{Di}'] \tag{9}$$

Color appearances of mathematical shading models in three conditions are described in equation (7)~(9). I_{ORG} shows the illuminated result from known the material properties and light conditions. The illuminant is usually considered as white.

In the case, we first convert the RGB value of I_{ORG} into XYZ primitives according to sRGB under D65 illuminant, then, convert XYZ primitives again into CIELAB color space. After applying a JND shifting vector, says ΔE^*_{ab}<2.3 at a specific direction, on the CIELAB of I_{org}, it can be inverted to I_{JND}. The material properties are obtained as in equation (8). In other words, two different material properties have no perceptional difference under the same illuminant. Once we replace the illuminant as violet light source, the illuminated color will be I_W. Moreover, we let the perceptional difference between I_{JND} and I_W as obvious as possible.

Multiple view texturing
In dealing with the texture of 3D model, we develop a software interface based on multiple view texturing. Our proposed method focuses on integrating with 3D graphics shading. Nevertheless, it is still available for 2D case under the same mathematical shading model. An example is shown in Figure 3(a). Initially, a digital model is generated by 3D scanner and eight texture images are obtained simultaneously. To compose a quality color 3D model, these images are directly cast on the surface of the 3D model. In overlap region, a vertex color may come from several visible images. Thus, we linearly blend the colors for each vertex according to a weighting function, which depends the distance and inclined angle between the vertex and images.

In Figure 3(a), the watermark is initially set on one of the texture images. Then, a synthesis process is carried out based on multiple view texture. Therefore, the watermark is again mixed with other view images, and finally it becomes a part of the 3D model.

In another scenario, for example in Figure 3(b), the watermark is considered as additional texture image with translucent channels. In this scenario, eight texture images are initially blended and cast on the surface of this 3D model. Then, the additional image with a watermark pattern is cast again according to the JND shift values for the watermark region.

In both cases of Figure 3, they are able to have a watermark on the model surface. However, in the first case as Figure 3(a), the watermark may be incautiously destroyed, and it is unlikely to have a hidden watermark. Nevertheless, the case in Figure 3(b) is the feasible solution for generating a hidden watermark.

(a) A pattern is assigned on one of the projecting images

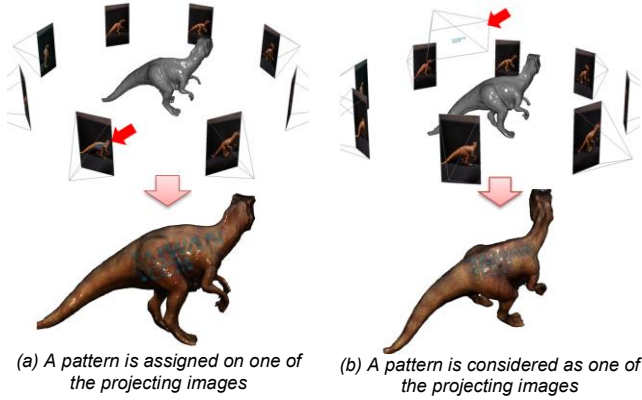(b) A pattern is considered as one of the projecting images

Figure 3. The experiment results show the colored model from multiple images

The overall flowchart of our proposed method is shown in Figure 4. It allows users creating JND patterns on 3D models. There are two categories for shifting the JND color. The first one is that the color is shifted along the longest axis of JND ellipse. This category can normally generate proper color shift. The second one is shifting along the direction toward the given color. This category may fail due to the ambiguous direction away from JND ellipse.
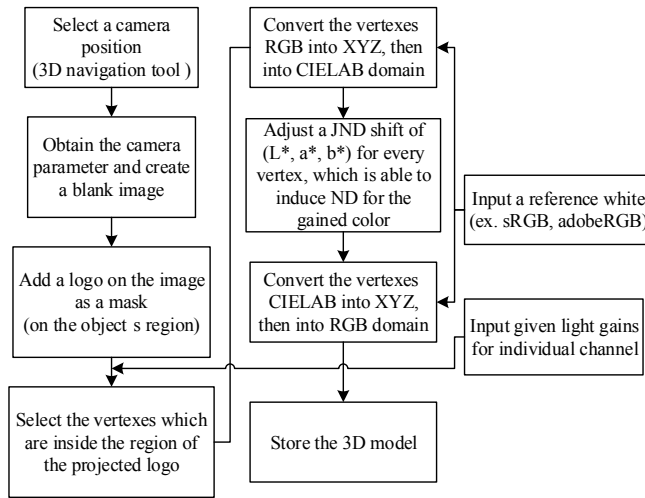

Figure 4. flowchart for generating JND watermark on the 3D model

Specific light for retrieving watermark

Though, the watermark can be hided under white light, it is still a problem for selection of the specific light in order to retrieve the watermark.

We assume the so-called violet light relative to the white light is with additional gain value on each channel. It can be described as equation (10). The gain values α, β and γ are corresponding to r, g and b channels of I_{Di} for determining the specific violet light.

To obtain proper gain values for most I_{JND} and I_W, we test all combination of 24bit material colors and 1 million gain values, then we determine a proper violet color which will induce that at least 90% material colors are perceptively different, says $\Delta E^*_{ab}>2.3$, after using the violet light. The main reason we use

brute force method to obtain the three gain values is that the conversions among colorimetric representations are not all linear [5].

$$I_{Di}' = \begin{vmatrix} \alpha \\ \beta \\ \gamma \end{vmatrix} I_{Di} \qquad (10)$$

Result and Discussion

In determining the specific light for retrieving watermark, we find that the potential light will be constrained in a relative low gain value for r channel, and much low gain value for g channel. The result in Figure 5 shows this phenomenon. After testing 24 bit colors, the average color difference will be larger than JND. Once the average ratio is two time of JND, it is significantly different. The recommendation of the specific light will consist of less r and g values as approaching the left-bottom corner in Figure 5. For example, the light with [0.2, 0.2, 1.0] will have around two time of JND to enhance the watermark and to be noticeable.
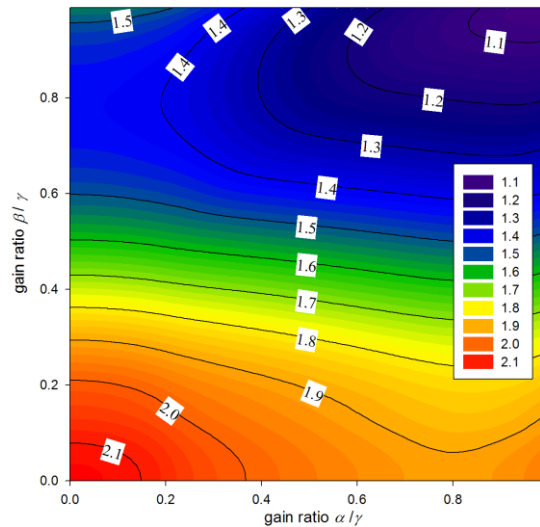

Figure 5. The average ratio to JND for 24bit colors

Although Figure 5 provides a guidance for selecting specific for retrieving watermark, another drawback follows. Figure 6 shows the variance ration to JND for each condition of specific light. The gain value for r channel do not significantly change the variance of color difference. And the g channel is recommended to be around 0.6 to have small variance. Once the gain values are selected, a look-up-table (LUT) is required to record the extreme trade of every colors for 24bit. Our LUT of the shifting values of all 24bit colors is determined by brute-force method.

One result is illustrated in Figure 7. We cast a watermark on the surface of a kangaroo model. Figure 7 (a) and (b) are the model with and without hidden watermark, respectively. Both of them are under the exact same lighting condition, says one white light source in front of the model. With comparison between them, most subjects can't notice the difference. By contrary, the pattern is readily noticed under specific lighting conditions as in Figure 7 (c) and (d).

With regard of the limitation, our method is not able to deal with intricate pattern surfaces. This is because the "difference" of color on the watermark is with comparison to its neighbor.
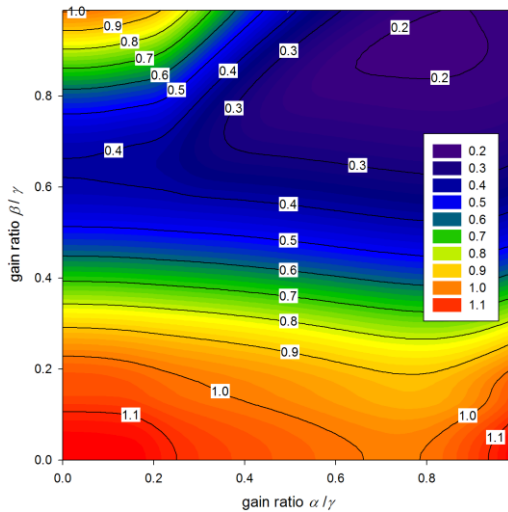

Figure 6. The variance ratio to JND for 24bit colors

(a) The original model with white diffuse and specular shading

(b) The watermarked model with white diffuse and specular shading

(c) The watermarked model under purple light (diffusion and reflection)

(d) The watermarked model under purple light (diffusion and reflection)
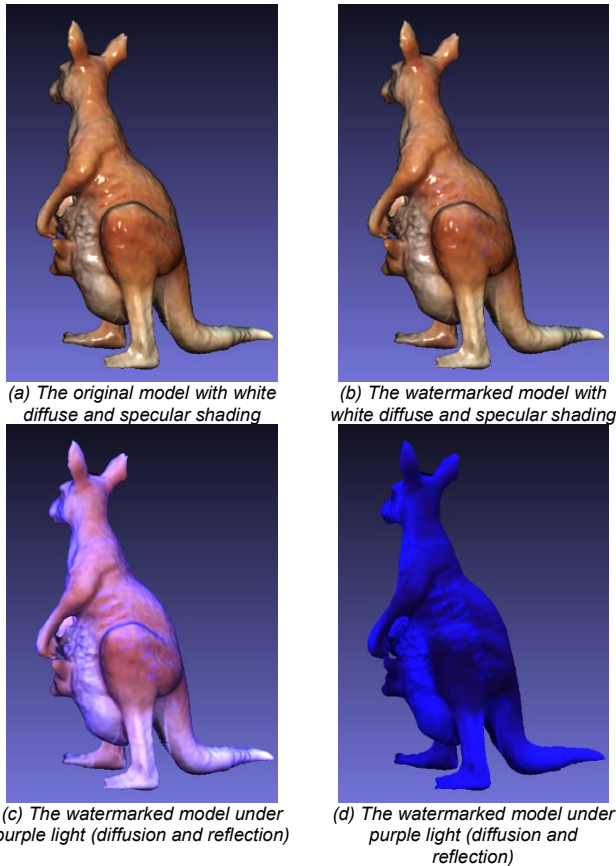
Figure 7. The experiment results show a hidden "TAIWAN TECH" watermark on a kangaroo model under different lighting sources

Conclusion

We propose a hidden watermarking for digital 3D models. It is an idea utilizing the property of just noticeable color difference and integrating with computer graphics. This idea is applicable in overlapping a watermark onto color 3D models, either in texturing image or models with color vertexes.

The gain values for specific light source are recommended to have small *r* and *g* channel simultaneously. However, it still has disadvantage for hiding a watermark for intricate colors in the same time. And the resolution of the watermark is also a limitation regarding human visual perception and need to be investigated.

References

[1] S. Izadi, et. al, "KinectFusion : Real-Time Dynamic 3D Surface Reconstruction and Interaction," in *ACM SIGGRAPH*, 2011.

[2] K. Kolev, P. Tanskanen, P. Speciale, and M. Pollefeys, "Turning Mobile Phones into 3D Scanners," IEEE Int. Conf. Comput. Vis. Pattern Recognit., pp. 3946–3953, Jun. 2014.

[3] R. Ohbuchi, "Watermarking a 3D shape model defined as a point set," *Proc. Cyberworlds*, pp. 1–7, 2004.

[4] M. Mahy, L. Van Eycken, and A. Oosterlinck, "Evaluation of uniform color spaces developed after the adoption of CIELAB and CIELUV," *Color Res. Appl.*, vol. 19, no. 2, pp. 105–121, 1994.

[5]   B. Fraser, C. Murphy, and F. Bunting, *Real World Color Management*. Peachpit Press, 2004.

Acknowledgment

Author Biography

Tzung-Han Lin received his Ph.D. in Department of Mechanical Engineering from National Taiwan University in 2006. He joined Industrial Technology and Research Institute as a senior engineer in 2007. He is currently an Associate Professor of Graduate Institute of Color and Illumination Technology at National Taiwan University of Science and Technology. His research interests include 3D data acquisition, 3D reconstruction, computer vision and computer graphics related topics.