Cel Shading 3D Rendered Image Using Color Thresholding in HSV Color Space

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***Abstract*—Cel shading is a shading technique of using flat colors to achieve the look of traditional 2D animation. In 3D rendering pipeline, the shading process is integrated into the rendering process by means of object surface material. Cel shaded material looks flat in color for a specific range of color luminance. In accordance with this property, we introduce an approach to cel shading that is separated from the rendering pipeline. Our cel shading approach is based on color thresholding in HSV color space. By thresholding the hue, saturation, and value of 3D rendered image, it bins all the colors into separate categories. For each category, our approach replaces the varying colors with a single flat color. Our approach manages to convert smooth shaded rendered image into cel shaded image without significantly degrading the visual look. Using this approach, a smooth shaded image or realistic image can be turned into a stylized image without additional information regarding objects or surfaces on the scene.**

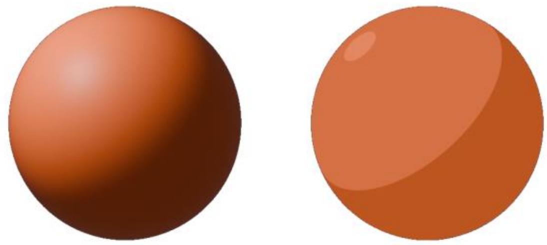
***Keywords*—cel shading, thresholding, HSV**

I. Introduction

Rendering is a process of constructing an image based on a description of a three-dimensional scene [1]. Based on the constructed image style, rendering can be done in two ways: photorealistic and non-photorealistic. Photorealistic rendering aims to generate a realistic looking image which is similar to a photograph of real-life scene. To achieve such goal, photorealistic rendering process is carried out based on physics laws. This technique is called phyiscally based rendering [1].

Aside of generating a realistic looking image, rendering can also be performed to generate a stylized image. A stylized image differs from a realistic iamge in terms of how objects are colored or shaded. To obtain a stylized image, one can apply a non-photorealistic shading technique to color objects in a scene. On of such technique is called cel shading.

Cel shading, also called toon shading, is a shading technique which aims to replicate the look of traditional 2D animation cels using flat colors [2]. In contrast to realistic shading, cel shading uses only a few numbers of different colors to shade multiple points or pixels with various brightness values or luminance. While realistic shading an object results in gradient color across the surface of the object, cel shading an object results in quantized color across the surface. Fig. 1 shows how cel shading differs from realistic shading visually.



(a) (b)

Fig. 1. An orange colored ball shaded using (a) realistic shader and (b) cel shader.

As shown in Fig. 1, the color of a realistic shaded object appears continuous, i.e., has a gradient transition of colors from light shaded points to dark shaded points. On the other hand, a cel shaded object displays an abrupt change of color from light shaded points to dark shaded points. In consequence, the cel shading an object causes the object to look cartoony as opposed to realistic shading that looks realistic.

In practice, cel shading an object in 3D rendering pipeline is done by applying cel shaded *material* to the object. An example [3] of how this material is constructed shows an approach to cel shade a point on the surface of an object by quantizing the color output of the material based on the color output of another shader. In more detail, to cel shade an object, we can use another shader to shade the object then quantize the color output based on the initial color luminance. As an example, following [3], a simple cel shader pipeline implemented in Blender is shown in Fig. 2, which is also used to construct cel shaded material for 3D rendered ball in Fig. 1(b).

Fig. 2. Simple cel shader material pipeline in Blender.

As seen in Fig. 2, we can observe that the input of color quantization, depicted as *Color Ramp* node, is a scalar equivalent of the color output of the base shader, depicted as *Diffuse BSDF* node. According to [4], the said scalar is the luminance value of the color. This practical approach of cel shading objects in 3D rendering strikes an idea to us to develop an approach of cel shading 3D rendered image. In contrast to material-based cel shading, our approach of cel shading is applied to an already rendered image instead of object surface during rendering process.

II. Terminology

A. Shading

We refer to shading as assigning a color to a certain point on a surface of an object. A point can be shaded in two ways: realistic and non-realistic. We refer to realistic shading as a way of shading which produces a photorealistic image. Hence, the term realistic shading in this paper is related to physically based rendering technique. As opposed to realistic shading, a non-realistic shading produces a non-photorealistic or stylized image. Cel shading is a kind of non-realistic shading. We refer to cel shading as a shading technique which colorizes object surface with discrete shades. Simply put, cel shading produces an image which is similar to Fig. 1(b) in style.

Apart from cel shading which yields discretes shades on object surfaces, a stylized image may also be rendered using a shading technique which yields gradient colors. However, these shading techniques may not be realistic in the sense that they do not obey physics laws. To generalize the terms, we refer to these kind of shading techniques as smooth shading.

B. Thresholding

Thresholding is the process of mapping a range of pixel values within an image to a single pixel value [5]. To be more specific, we refer to the term thresholding as mapping of pixel values in RGB color space with respect to what is being thresholded. Thus, *hue thresholding* does not mean mapping a range of color hues into a single hue. Instead, by hue thresholding we mean mapping pixel values which are within a range of hue values into a single pixel value in RGB color space.

C. Scene

In 3D rendering, a scene represents a setting of an environment which contains various 3D objects, lights, and cameras. We refer to a scene as the mentioned definition. Additionally, we also refer to a scene as the 3D rendered image of the corresponding environment. In this paper, we use the term scene to describe both definitions.

D. Material

Material describes the appearance properties of each point on the surface of an object [6]. Hence, the material of an object surface describes how the said object surface looks when it is rendered. In other terms, a material is the characteristic of how a surface of an object looks, including, shiny, opaque, transparent, reflective, emissive, etc. In addition, a material also often describes the substance that composes an object. For example, one could say an object has a wooden material, metallic material, or glassy material.

III. Methods

As stated, a practical approach [3] of cel shading an object in rendering process is to quantize the color output of other shader based on its luminance. However, cel shading an image implicitly requires us to identify the objects within the image since cel shading each object in 3D rendering process can be done independently. Since identifying and segmenting each object automatically is not an easy task, we approximate object identification and segmentation by categorizing the colors in the image. The categorization is performed by thresholding pixel color hues.

Aside from hue thresholding, we need to assign different shades to each hue category. A naïve approach to shading each category would be to threshold the luminance of the colors, which is given by Y channel in XYZ color space [7], in each category. In addition, we also need to threshold the color saturation to take desaturated colors such as white, gray, and black into consideration as possible separate objects.

While the naïve approach of shading using luminance thresholding works, we found empirically that luminance thresholding is not suitable with hue and saturation thresholding. Instead of luminance, we found that thresholding the third channel in either HSV or HSL color space yields a better result of cel shaded image. Furthermore, we also found that HSV color space yields a slightly better result visually. Fig. 3(a) and (b) depict the difference between the result of value (V) and luminance (Y) thresholding of Fig. 1(a) with the same hue and saturation category.

(a) (b)

Fig. 3. Result of color (a) value and (b) luminance thresholding of Fig. 1(a).

We observe that using luminance thresholding yields unevenly sized shades and slightly noisier shade edges for the same hue and saturation category. Hence, we chose to threshold hue, saturation, and value of pixel colors in the HSV color space for our cel shading approach. The following sections explain in detail on how each channel is thresholded and how the final shade of color is obtained.

A. *Hue Thresholding*

In our approach of cel shading, we first threshold the hue of the colors in the image globally. Given a number of bounds, the hue is categorized using Otsu's thresholding method [8]. Nonetheless, we do not modify any color after the hue thesholds are obtained. Hence, we defer color modifications for the cel shading until we threshold saturation and value.

B. *Saturation and Value Thresholding*

Similar to hue thresholding, the saturation and value thresholding is also done globally. However, for saturation and value, we divide the range of the channels equally based on a given number of bounds. For example, if value is to be thresholded into 4 categories, the corresponding bounds would be 25%, 50%, and 75%. Similarly, if saturation is to be thresholded into 2 categories, the corresponding bound would be 50%.

C. *Shade Calculation*

With each channel on the HSV color space being thresholded, we end up with several bounds for each channel. Using these bounds, the cel shading process is done by replacing the colors belong to each category with a single color. In constrast to gray value thresholding, the color shade for each category is not calculated separately for each channel in the HSV color space. Instead, we collectively threshold all category and replace the corresponding colors with a single color. As an example, if hue, saturation, and value are thresholded with 2, 3, and 2 bound consecutively, there would be 36 categories of colors as a result.

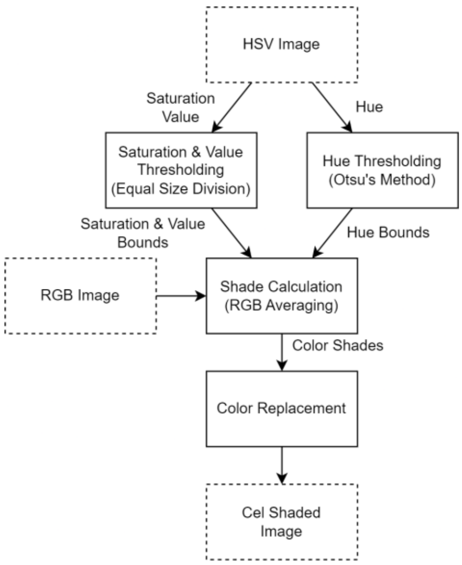
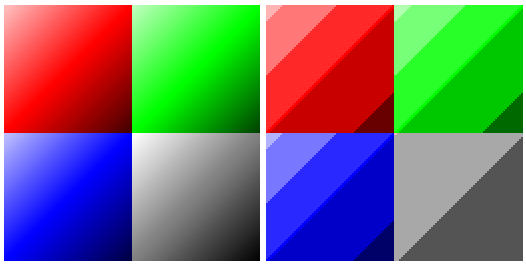


Fig. 4. Illustration of our cel shading approach.

Once the categories of color are obtained, we perform the cel shading by replacing all colors in each category with a single color. In our approach, this color is simply obtained by averaging all colors in RGB color space. We found empirically that this method of shading in a well looking image visually. Nonetheless, when the average is not the desired shade, one can simply map the average color to the desired color afterwards. All things considered, the steps of cel shading using our approach are ilustrated in Fig. 4.



(a) (b)

Fig. 5. Cel shading gradient image of primary colors and grayscale colors. (a) Smooth shaded primary colors. (b) Cel shaded primary colors.

To ilustrate the process of our approach, the result of cel shading gradient image of primary colors and grayscale colors is shown in Fig. 5. In this example, we use three hue bounds: 60°, 180°, and 300°. In addition, we pick 3 saturation bounds and 2 value bounds. As seen in Fig. 5, we observe that saturation bounds divide the lighter area into several regions whereas the value bounds divide the darker area as well as grayscale colors into several regions. By controlling these two bounds, we can try to achieve desired cel shading result of an image based on the pixels brightness.

IV. RESULT AND DISCUSSION

In order to see our approach of cel shading in practice, we tested it by cel shading 3D rendered image of various scenes. We picked various cases and effects of 3D rendered image such as motion blurs and emissive material to see how well our approach deals with varying style of images. Additionally, we also tested the approach on both realistic and non-realistic 3D rendered image. In summary, Fig. 6-9 portray the result of applying our cel shading approach into various 3D rendered images. A full implementation of our cel shading approach is accessible online on GitHub.

(a) (b)

Fig. 6. Motion blurred floating donut with (a) realistic shading and (b) cel shading.

(a) (b)

Fig. 7. Floating emmisive 3D Himpunan Mahasiswa Informatika (HMIF) logo with (a) realistic shading and (b) cel shading.

(a) (b)

Fig. 8. Stylized bakery scene with (a) smooth shading and (b) cel shading. (Scene courtesy of Nicole Morena)

(a)

(b)

Fig. 9. "White Lands" scene with (a) realistic shading and (b) cel shading. (Scene courtesy of Oksana Dobrovolska)

Recall that in our approach, each channel in the HSV color space is thresholded separately with its own number of bounds. In accordance, our tests depicted in Fig. 6-9 also used relatively different numbers of bounds for each channel on each image. Table I summarizes the number of bounds for each channel on every image in our tests.

TABLE I. NUMBER OF BOUNDS FOR EACH CHANNEL IN EACH SCENE

Scene	Number of Bounds			Hue Bounds
	Hue	*Saturation*	*Value*	
Donut	5	4	4	63.4°, 111.4°, 174.8°, 256.5°, 291.8°
HMIF	3	4	4	28.2°, 73.4°, 106.8°
Bakery	5	3	5	29.4°, 116.5°, 162.4°, 221.2°, 267.1°
White Lands	4	4	5	94.7°, 149°, 187.9°, 313.2°

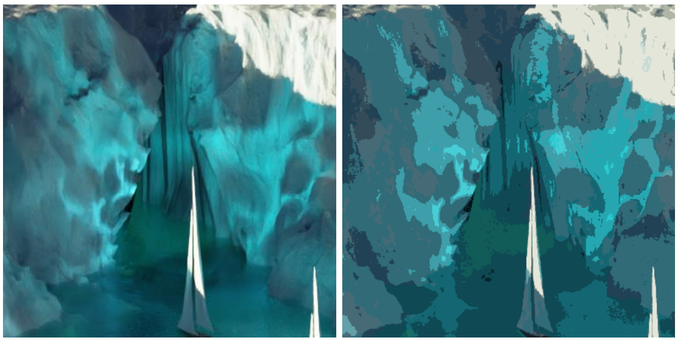
Looking back at the test results, we observed that our method is able to cel shade all rendered images fairly well without destroying their visual looks significantly. However, we noticed a disadvantage of our approach regarding edges within similar colors. In Fig. 6, we noticed that applying our cel shading approach with the parameters given in Table I completely removes the donut vague edge in the upper left area. Consequently, the background region is mixed together with the donut glaze region in the cel shaded image.

While the mixing of pink background and pink glaze can be avioded by increasing saturation bounds, adding more color categories for the cel shaded image results in visible noises on shade edges. As an example, these noises are also evident in emitted green ground in Fig. 7. Nonetheless, one could argue that these noises are part of cel shading characteristics. To see it more clearly, Fig. 10 shows visible noises on the cel shaded image.

(a) (b)

Fig. 10. Visible noises on cel shaded HMIF logo. (a) Smooth green ground on original image. (b) Noisy green ground on cel shaded image.

Despite introducing some noises, our approach works quite well on converting smooth shaded image to cel shaded image, especially in an image with low color hue variation such as Fig. 9. Notice that in Fig. 9, we can see our approach in action more clearly on the icy cliffside region. While the realistic shading in Fig. 9(a) picture the glowing blue ice in gradient, the cel shaded result in Fig. 9(b) portray a flattened shades of blue, providing more stylized characteristics. To see it more clearly, Fig. 11(a) and (b) depict the original smooth shaded icy cliffside and the cel shaded one.



(a) (b)

Fig. 11. (a) Smooth shaded and (b) cel shaded icy cliffside in "White Lands" scene.

Aside from low color hue variation image, the cel shading approach also works fairly well on high hue variation, i.e., in the "Bakery" scene image. Even though the shades are obtained by averaging, the cel shading approach did not cel shade image with a color that is too far away from the original color. This is possible due to a high number of bounds for thresholding the hues to approximately separate different objects. Moreover, the cel shading approach also captures shadows quite well over the entirity of the scene, apart from the bottom right wooden floor region. Fig. 12(a) and (b) show an example of cel shaded shadow of the underside of the sofa arm.

(a) (b)

Fig. 12. Captured shadows of the underside of sofa arm in "Bakery" scene. (a) Smooth shaded sofa. (b) Cel shaded sofa.

V. Future Work

As we have seen on the test results, our cel shading approach has some limitations. The first major downside of the cel shading approach is the mixing of regions having relatively similar color. To address this issue, we suggest future work to integrate a better method for object separation. For example, a future work may employ edge detection technique to detect edges in order to separate objects with similar colors in a better way. Moreover, edge detection techniques can also be used to create outlines on various objects which is occasionally desirable for cel shaded renders.

Another limitation in our approach is the visible noises on shade edges as an effect of thresholding. While the cel shaded image produced by our approach is visually not far from what we hoped, this side effect of thresholding in HSV color space is always present. In the future, we want to further investigate and possibly develop an alternative to separately shades various colors based on their luminance.

Another possible improvement to the current approach is to use a different method of thresholding for the hue channel. Although Otsu's method [8] is good to find threshold values, using this method to threshold hue values is suboptimal since the hue values in HSV color space have a circular order. Hence, we encourage future work to employ another method for hue thresholding, particularly circular thresholding methods such as [9] and [10].

VI. Conclusion

Cel shading is a shading technique which aims to replicate the look of traditional 2D animation using flat colors. The coloring or shading of object surfaces in 3D rendering pipeline with cel shading technique is usually integrated to the rendering process. The shading is done through the application of material on object surfaces.

A simple approach of cel shading in 3D rendering is to shade a surface with a flat color for a specific range of color luminance. Such luminance is obtained from a color that is shaded by another shader, e.g., a realistic shader. Using this technique, the rendered image appears stylized and cartoony.

Our approach of cel shading explores the shading technique further by separating the shading process from rendering process. Hence, it does the cel shading without any information about objects or surfaces on the scene. It utilizes color thresholding technique in the HSV color space to identify and separate objects as well as shade those objects in order to make the image appear stylized.

We tested the approach with various 3D rendered image with various kinds of materials and effects. Overall, our approach is able to cel shade the rendered images and turn them into a cel shaded images. However, the approach struggles to separate objects from background when the colors of the background and the object are similar. Additionally, the cel shaded images generated by our approach sometimes contain visible noises, especially on the shade edges.

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