Stylized Line Drawing and Shading Effects for Cartoon Rendering

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Abstract— **Due to increasing demands of cartoon style in many areas of computer graphic aspects, this paper presents a simple stylized shading technique to enhance the cartoonish appearance in two aspects. First, a new toon-illumination model is developed to emphasize the boundaries between diffuse reflection part and specular reflection part in the phong illumination model. The new discrete shading will be exploited to convey the light and dark orientations on the surface of 3D model. Second, we combine stylized lines with non-photorealistic shading effect to convey more visual cues of tone. The experimental result reveals the ability of proposed model to produce many cartoon effects.**

Keywords — **Non-photorealistic Rendering, Line Drawing, Cartoon Rendering, Phong.**

I. INTRODUCTION

Non-Photorealistic Rendering is a branch of computer graphics which concentrate on the algorithms that generate images in a diversity of artistic and illustrative styles [1]. Historically, producing images which are indistinguishable from the original is the main area of computer graphics [2]. In many cases the photorealistic is not the optimal solution for rendering the scene. In contrast, Non-Photorealistic image is important for conveying the information and adding the simplicity of complex objects. NPR images distinguished over photographs in many practical advantages such as lack of dispersion (e.g. in scientific illustration), focusing and clarification of essential details (e.g., in maps, caricature and technical illustrations) [3], [4].

Several methods exist to produce correct physically based shading, which are appropriate to covey the 3D model in realistic styles [5],[6]. However, for artistic purpose it is often to place the lighting sources in fictive positions as well as modifying the light direction or altering the light vertex to achieve the desired result. In this paper, we therefore present a new technique to enhance the cartoonish style appearance.

Toon-shading is a type of non-photorealistic rendering techniques developed in order to produce computer graphics output appear to be hand-drawn [7]. It often used to convey the cartoon-style at movies, video games and comic books. The intuitive end result of toon-shading is very simplistic and exaggerative 2D animation. The main feature of toon-shading is the hard edge that separates between the shadowed and illuminated colors on the surface of 3D model as well as hard edge that separates the highlighting cue from the main material color. Fig. 1 depicts these cartoonish features.

II. RELATED WORK

Because of the wide range of related work in the area of non-photorealistic rendering, this section covers the substantial body of the following two categories: non-photorealistic lighting models and stylized line drawing.

Gooch et al. [8] was a pioneer in introducing a non-photorealistic lighting model for technical illustration based on adding two tone-colors (warm color and cool color) to convey the perception depth of the object. In [9], a new shading technique based on modifying the light diction according to surface geometry features is proposed. It enhanced the comprehension of complicated model details. In same context, Rusinkiewicz et al. [10] introduced a non-photorealistic shading model based adjusting the light position according to the smoothed normals. It applied multi-scale of shading to convey details of the underlying model at all frequencies.

In context of cartoon rendering, Lake et al. [7] proposed a very efficient real-time cartoon method to render cartoon style. It based on the hard shading technique that relies on mapping one dimensional texture. Barla et al. [11] extended one dimensional texture to two dimensional textures in order to support view-dependent effects, such as depth perception and abstractions levels. Several techniques exploited this approach to convey more visual features such as visual saliency [12] and material depiction [13].

In order to provide users more ability to control the stylized shape appearance over 3D model, several techniques have been proposed that modify the shade effect. One of the works that the attention in this context was [14]. They proposed a method to manipulate the highlight shape in stylized appearance. In [15] a new method to modify stylized light and shade is proposed, It allows controlling some operations such as splitting, scaling, rotation and translation on shaded regions. The work in [16] follow the same idea, presenting a controllable shading method to manipulate the shading and lighting distribution over the surface of 3D model in direct intuitive panting approach.
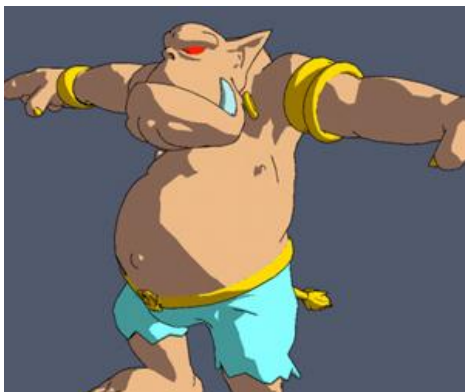

Fig. 1. Olaf rendered using cartoon shading [7]

One of the biggest challenges faced the researchers in non-photorealistic rendering is how to produce computer generated images like hand-drawn artist [17]. Decaudin et al. [18] described the first toon-shading method to render the cartoon style. They started with generating the outline edges on 3D objects based CPU implementation. For models with a huge number of polygons, this method is expensive and produce poor outline edges. Silhouette detection, rendering and stylizing are very important for Toon shading and for Non-Photorealistic Rendering in general. Important techniques are presented for the silhouette detection [19], [20],[21].

Isenberg et al.[22] classified all silhouette detection techniques in three groups, image space algorithms which focus on image processing , the second group is object space algorithms which are divided in two groups, free form and polygon mesh and final group is hybrid algorithms. In compare by finding accuracy silhouette and appropriate stylization the second group algorithms are better than the [23].

III. TOON ILLUMINATION MODEL

Toon-Shading considered one of the most NPR techniques to express a great amount of information by using a limited number of colors, silhouettes and sharp features [7]. Two of the most interesting visual styles are cartoon-style rendering and sharp features. This work presents a combination if these vital features in one non- photorealistic style in order to improve the shape perception and overall appearance.

A. Stylized Light and Shade

Formulating the light equation that describes the interaction between light source and the properties of the object surface is the first step in creating the Toon-shader. The simplest way to describe the light reflection from surface is phong lighting model [24] which combined three types of lighting: Ambient, diffuse and specular to convey the final result of light reflection. Traditionally, this type of refection model can effectively convey the photorealistic style. This work exploits phong lighting model to create non-photorealistic style capable of enhancing the cartoonish appearance. Here we are going to explain how phong model can be simplified to emphasize the boundaries between the reflection parts (diffuse and specular) to create a hard edge that separates between the surface colors and enhance the no-realistic style. The next formula can express the phong lighting model

$$C_i = a_l \times a_m + Max(L.n, 0) \times d_l \times d_m \quad (1)$$

Where C_i is the vertex color, a_l is the ambient coefficient of light, d_l is the diffuse coefficient of light, a_m is the ambient coefficient of the object's material, d_m is diffuse coefficient of the object's material, L is the light unit vector and n is normal unit vector surface at the vertex. We can note that the specular part is omitted since to the realistic behavior that give to 3D model. The main contribution of phong lighting model is the smoothing while transition from ambient to diffuse color. But as we mentioned before, the main attribute of the toon-shaded image is the hard edge that divides the light area and the shaded area. This look of traditional cartoon can be achieved by using threshold for each two colors and applying the discrete numbers for colors. This can be achieved by replacing the $Max(L.n, 0)$ in (1) by a threshold function that defined as:

$$thresh\ (a,b) = \{0\ :\ a < b\ ,\ 1\ : a \geq b \quad (2)$$

Now we can reformulate (1) with new function $thresh\ (a,b)$ to define new lighting equation as

$$C_i = a_l \times a_m + thresh\ (L.n, t_h) \times d_l \times d_m \quad (3)$$

Where t_h is the diffuse threshold$(-1 \leq t_h < 1)$. This produces the desired effect of creating the hard edge between the illuminated area and shadowed area. The new threshold t_h parameter can effectively control the relative sizes of illuminated and shadowed areas. Small value of t_h creates small dark area and large illuminated area and vice versa for large values of t_h. The flat-Shaded color that consists of one color can be achieved through setting t_h to 1 or -1.

Although the specular term is omitted from our phong lighting model , Most of the artists desire to add a third color to the object which represents the highlight of the shape to symbolize the shiny surface[14],[15]. Therefore, it is necessary to render this type of lighting in non-photorealistic style for enhancing the cartoonish style. Specular term in phong lighting model is expressed

$$C_s = S_l S_m (L.v)^n \quad (4)$$

Where S_l the specular is light, S_m is the material color, L is the light unit vector, v is the view vector and n is the shininess coefficient of highlight. Now, the simplified phong lighting model combined three different types of lighting separated by hard edge to enhance the cartoonish style. Formula (5) can express this

$$C_i = a_l \times a_m + (thresh(L.n, t_h) \times d_l \times d_m) + (thresh\ (L.v, t_c) \times S_l \times S_m \quad) \quad (5)$$

Where t_s is the diffuse threshold $(-1 \leq t_s < 1)$.

B. Stylized Line Drawing

A variety of vital properties such as simplicity, easy to use and power of abstraction makes line drawings a key technique in Non-photorealistic Rendering, as well as makes it commonly used in many computer graphics fields such as animations, sketches and technical illustrations.

Silhouettes edge detection is very important to describe the basic shape of an object [25]. Also, it is considered as a very necessary step to produce a Toon-Shader. Moving the objects or the viewpoint (eye point) requires recalculated the silhouettes, since they are viewed based dependencies. This calculation has updated at each frame in real-time or interactive systems. There are two main methods to detect the silhouette edges, image space and object space methods.

An edge is considered as a silhouette if connected front-facing polygon to back-facing polygon [26]. A front-facing polygon is possibly visible, but the back-facing polygon is completely invisible to the viewer. Fig.2 illustrates the

silhouette edge which represents the connection edge between front-facing polygon and back-facing polygon.
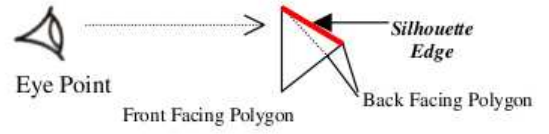

Fig. 2. Silhouette edge detection [7]

The silhouettes should be computed at each keyframe by calculating the dot product between the vector normal and viewing vector for the two faces adjacent to a specific edge. Then the result of these two dot products compared with zero. The edge is marked as silhouettes if the final result of this equation is less than or equal to zero. The following equation can formulate this process

$$(FaceNormal1.eyeVect) * (FaceNormal2.eyeVect) \leq 0 \quad (6)$$

Once the silhouettes have been detected, the stylization process can be applied which based on increasing the thickness stroke which approximate to dark regions of the shaded parts.

IV. EXPERIMENTAL RESULT

The final results of this research show that our stylized shading technique can effectively produce cartoonish appearance for 3D models in two styles. The proposed technique was tested with NVIDIA GeForce GT 525 M display card and Intel (R) Core (TM) i7-2630 QM CPU. Several models are rendered by our toon-illumination model. Figures 3&4 illustrate the difference between phong lighting model and toon-illumination model results. Fig. 4a illustrates the effect of phong lighting model on 3D model sphere. In Fig. 4b, uses the proposed toon-illumination model to create a hard boundary that separates between colors for enhancing the cartoonish effect. Our proposed shading with stylized line drawing is shown in Fig. 4c.

A more complex model is shown in Fig. 5 which illustrates the comparison between photorealistic Boboiboy model (see Fig. 5a) and our toon-shading style on Boboiboy model (Fig. 5b).
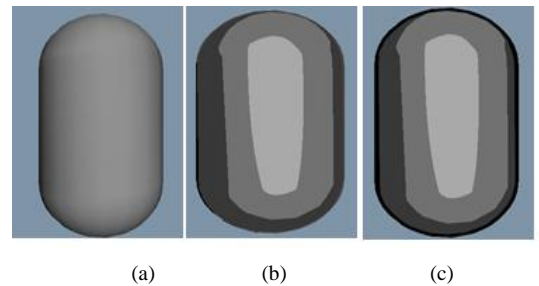

(a)   (b)   (c)

Fig. 3. Comparison between Phong and Toon illumination model. (a) Phong illumination model. (b) Toon-illumination model. (c) Toon-illumination model combined eith stylized line drawing
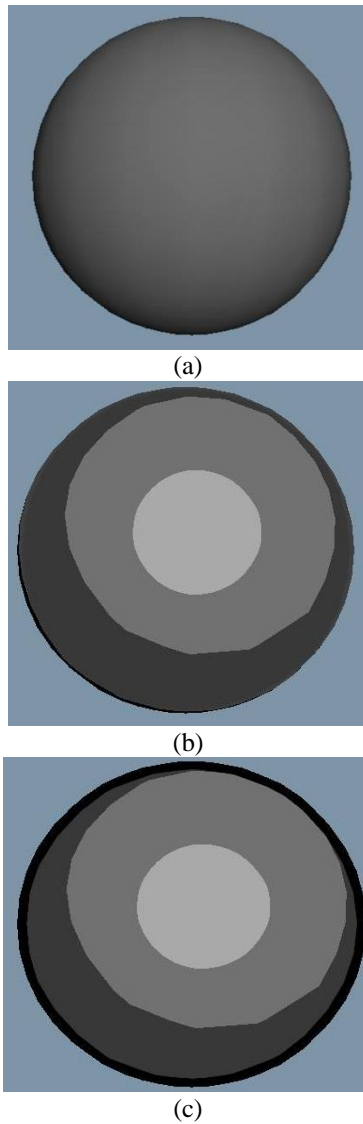
Fig. 4. Comparison between Phong and Toon illumination model. (a) Phong illumination model. (b) Toon-illumination model. (c) Toon-illumination model combined eith stylized line drawing
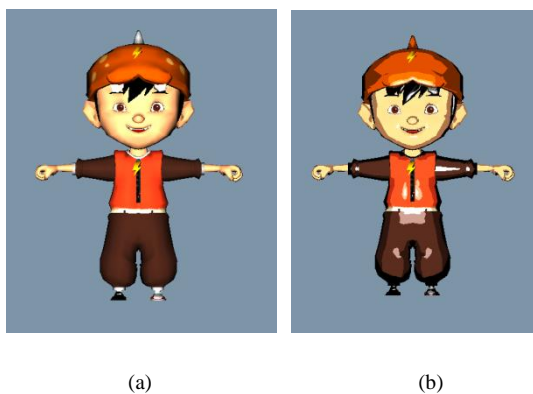

(a)   (b)

Fig. 5. Comparison between photorealistic and Toon illumination model. (a) photorealistic Boboiboy model. (b) Toon- illumination Boboiboy model.

V. CONCLUSION

In this study we were able to propose a toon- illumination model which combines the shading effect and stylized line drawing. This illumination model can be applied on a wide variety of 3D models with more ability of controlling the shading appearance over the surface of 3D model. This ensures better shape depiction and faster solutions to reach the desired results. However, the model we have presented is tailored to convey the material appearance as well as the depiction of complex details. The further limitation concerns to aliasing which occurred on the hard boundaries between colors.

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