ART DIRECTED WATERCOLOR SHADER FOR NON-PHOTOREALISTIC RENDERING WITH A FOCUS ON REFLECTIONS

A Thesis

by

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ABSTRACT

In this research, I demonstrated that emulating painterly reflections is impossible using existing modeling, compositing and rendering software that does not provide programming capabilities. To obtain painterly reflections, we need to emulate three aspects of painterly reflections: (1) shape of reflections; (2) glossiness of reflections; and (3) colors of reflections. The first two turn out to be relatively easy. However, despite the perceived simplicity of color reproduction, the third one turned out to be hardest without developing our own proprietary tools.

To demonstrate the difficulty, I have developed a shader using commercial rendering and shading software that does not provide explicit programming power. I assigned my shader as a surface material to 3D objects. Using my shader, I was able to create computer generated watercolor style renderings without reflections. My shader provide rendering effects such as diffuse, contours, specularity, shadow, and reflections. Although I can faithfully emulate non-reflected regions of given water-color paintings, I demonstrate that my shader cannot produce reflection colors that are faithful to colors of original reflections.

To my family, friends, and my kitty Miu Miu.

ACKNOWLEDGMENTS

I would like to thank my committee chair, Professor Ergun Akleman for his support all the time and his patient guidance throughout my three years' graduate study and the process of this research. I am truly thankful for his trust and patience. It has been a great pleasure to have the opportunity to work in the Viz lab for these years. I would also like to thank my committee members, my co-chair Professor Richard R. Davison, Jr. who helped me discover new perspectives not only in art and also in life, and Professor Rodney C.Hill for kindly being on my committee. Thank you all for giving me suggestions and feedback that enriched my research.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Professor Ergun Akleman and Professor Richard R. Davison, Jr. of the Department of Visualization and Professor Rodney C. Hill of the Department of Architecture.

The basic shading network of the Barycentric Shader Maya was built by Yuxiao Du from her Charcoal shader. The watercolor shader in this thesis is using the same core method as the Charcoal shader with several new modifications for the watercolor look.

The matrix used in this research to achieve the reflection colors are calculated by Carl Van Huyck with his Reflection Filter Program.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

There are no external funding sources involved in this thesis.

NOMENCLATURE

2D	Two Dimensional
3D	Three Dimensional
CG	Computer Graphics
UV	The U and V Axes
NPR	Non-Photorealistic Rendering

TABLE OF CONTENTS

Page

LIST OF FIGURES

FIGURE Page

1. INTRODUCTION AND MOTIVATION

In this chapter, I explain the motivation and my personal background behind this research work, and then introduce the goal of this project and the framework it is based on. There is a brief review of my previous CG and traditional work involved. Key concepts and algorithms that this research uses will also be discussed as well as the motivation of using them.

1.1 Traditional Art Work in CG

(a) (b)

Figure 1.1: Watercolor Painting (a) "Blue Bear" and (b) "Dream" by Ji Cheng

Nowadays, more and more traditional artworks are transforming to digital forms, which provide artists with a more efficient, flexible platform with easy accessing, changing and sharing features. For example, today's Japanese anime use an increasing amount of the

3D elements for an easier control in their 2D animation production. To achieve a variety of 2D styles in the 3D environment is an important topic in the film and animation fields.

Watercolor is like no other medium. Its vibrant colors and spontaneous shapes give it a distinctive charm. [16] Watercolor offers a very rich medium for graphical expression. As such, it is used in a variety of applications including illustration, image processing and animation. [17] Among all kinds of traditional media, watercolor has its own charm of the unpredictable freeform quality, which many artists are fond of.

(a) (b)

Figure 1.2: Chinese ink painting (a) "Plum Blossom" and (b) fan painting by Ji Cheng

Personally, I find that watercolor shares a similar nature with the Chinese traditional ink painting/sumie painting.Figure 1.1 shows my watercolor paintings. Figure 1.2 shows my Chinese traditional Ink Painting "Plum blossom" and the fan painting. I have had many years of experience in Chinese traditional ink painting and I have always been fascinated by watercolor although my study focus is shading and texturing in CG. Other than water-

color and Chinese traditional ink paintings that were mentioned in the beginning of this paper, I am also interested in many other different media including charcoal, acrylic, oil. Figure 1.7 shows two of my oil paintings "FLEDGE" and "REVIVE" which were exhibited in the Space Show at Viz North Gallery in Downtown Bryan Texas and the exhibition of Vizagogo24 (A annual showcase of student work in the Department of Visualization at Texas A&M University).

I have strong interests in traditional paintings and I am also very passionate for Computer Generated art especially in surfacing and shading. Thus, I find it interesting to work on something that combines both my interests: watercolor and CG together and I hope to explore the possibilities for the stylized reflections in current 3D software. In fact, watercolor look rendering in computer graphics has been a very popular topic over the years. There are many studies conducted in a related field from real-time watercolor rendering of a 3D scene to digitally transforming a photo to a watercolor painting etc. However, there's no research specifically on the study of the reflections of watercolor in CG. Therefore, I find the importance in conducting my studies of the reflections of watercolor style rendering in CG.

The reflection in the natural world is a special form of beauty as shown in the Figure 1.3. Many artists tend to study and express this kind of beauty in their artwork. Figure 1.4 shows the watercolor reflections and water exercises of Rob Dudley. From his watercolor paintings, we can see many different forms of reflections painted, and see how the artists use the nature of watercolor to mimic the natural water flow and the reflections on the water surface.

Andy Walker demonstrates three different types of reflections of the windmills in watercolor paintings as shown in Figure 1.5. The reflections vary in color, shape and wave frequency. They all look believable while representing the same object, the windmills, with different looks of the reflections on the lake surface in different weather conditions

(a) (b)

Figure 1.3: Photography of the reflections on the lakes in the South Islands of New Zealand by Ji Cheng

eg: sunny, windy, cloudy/gloomy. His watercolor paintings are really simple to test the power of existing software by recreating them in CG. So after considering several watercolor paintings with reflections, I chose this set of windmill scenes as my test case.

1.2 My Previous CG and Traditional Work

Figure 1.6a shows the photo reference of the abandoned balcony scene and Figure 1.6b shows my rendering result of it. Figure 1.6c shows the photo reference of the yoga stone scene and Figure 1.6d shows my rendering result of it.

The comparision between the photo references and my renders side by side demonstrates my skills as a 3D artist. For photo realistic scene, base on my shading and texture skills, I was able to achieve a faithful rendered results. Here are two examples of my previous shading work. The first one is a yoga stone scene built in Maya and rendered with Renderman. All Shading are procedurally created by adding layers of noise on top of each other. With the physically based lighting, the final render result is very close to the reference photo image on the right side of the image.

There's no UV unwrapping involved in this particular project. Everything is procedu-

Figure 1.4: Watercolor reflections and water by Rob Dudley [1]

rally created by connecting the nodes in the shading network in Maya. The second one, the abandoned balcony scene is also modeled in Maya and rendered with Renderman. The difference is that all the texture maps are created in Mari while all the objects are UV unwrapped in order to paint in Mari. The final result also very believable and is close to the targeting photo on the right side. These two examples demonstrate that photo realistic rendering is achievable with the commercial CG software Maya and Renderman and also demostrate the textureing and shading skill levels that I have as a surfacing artist and an advanced user for Maya.

In my research, I recreated the windmills scene in the three-dimensional space and then studied and create the reflections of the windmills for different reflection looks by using

Figure 1.5: Watercolor Paintings by Andy Walker [2]

my watercolor shader. My goal is to explore the possibilities for achieving a believable watercolor painterly look with the 3D scene rendered with Mental Ray in Maya.

(a) *Original Photo of the Balcony*

(b) *Computed Render for the Balcony*

(c) *Original Photo of the Yoga stone*

(d) *Computed Render for the Yoga stone*

Figure 1.6: (c) (d) Yoga stone and (a) (b) Balcony rendered scenes with the photo references on the left

(a) (b)

Figure 1.7: Oil paintings on canvas 18 x24’ (a) FLEDGE (b) REVIVE by Ji Cheng

2. LITERATURE REVIEW

My research mainly focuses on non-photorealistic rendering. Since my goal is to build a universal watercolor style shader in Maya, the foundation of non-photorealistic rendering in CG in the rencent decades and the concept and previous work of watercolor study in CG would be studied.

2.1 NPR Trend in the Movie Production

The advent of photography and computers has not replaced artists, illustrators, or draftsmen, despite rising salaries and the decreasing cost of photographic and computer rendering technology.[18]

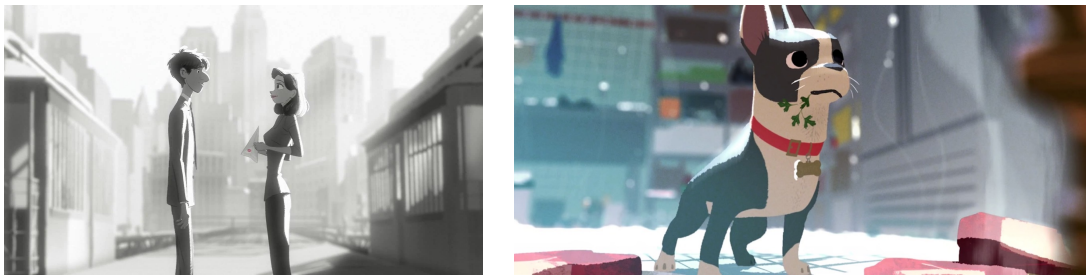


Figure 2.1: Paperman (2012) Scene [3] and Feast (2014) Scene [4]

Although photorealistic rendering in CG is achieving an increasingly advanced level of realism, which could fool human eyes, artists never stop exploring non-photorealistic work. A good example could be Disney's shorts "Paperman" and "Feast" in Figure 2.1. "Paperman" (stylized as paperman) is a 2012 black-and-white 3D romantic comedy short film. Produced by Walt Disney Animation Studios and directed by John Kahrs, the short blends traditional animation and computer animation. [3] Also the 2014 American 3D

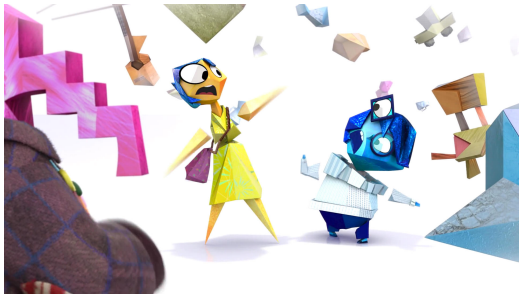
Figure 2.2: Book of Life (2014) Scene [5] and the Concept Art of Wish Police (2018) [6]

Figure 2.3: The Peanut Movie (2015) [7] and The original Snoopy Comic [8]

hand-drawn/computer-animated romantic comedy short film "Feast" achieves these qualities. There's a trend for these kinds of more stylized painterly looking animations in the animated film field. Similarly, Reel FX studio released a colorful stylized original in-house movie Book of Life in 2014 which features Mexican culture and the celebration of death shown in Figure 2.2 on the left,and then since 2016 Reel FX has been creating a new full length feature film "Wish Police" with a very stylized painterly look rendering shown in Figure 2.2 on the right. Figure 2.3 on the left shows "The Peanut Movie" created by Blue Sky studios with a very stylized painterly looking render which is aiming to be loyal to the original snoopy comics shown in Figure 2.3 on the right.

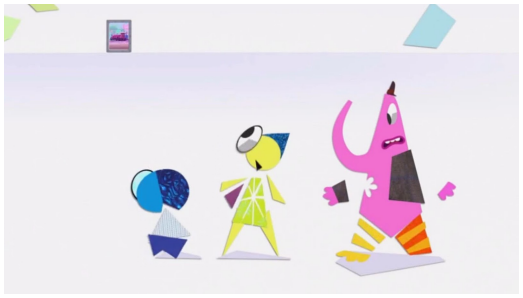
(a) *Epic 2015 Pixar Movie "Inside Out"*

(b) *Joy and Sadness inside an active Abstract Thought*

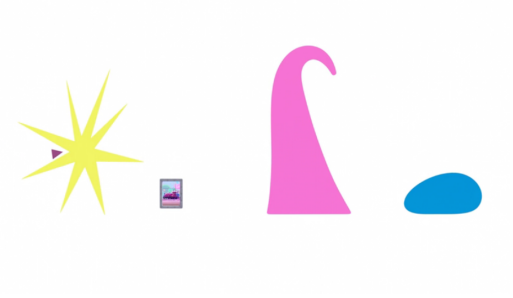


(c) *Stage One: Non-Objective Fragmentation*

(d) *Stage Two: Deconstruction*



(e) *Stage Three: Two-Dimensionalzation*



(f) *Stage Four: Non-Figurativity*

Figure 2.4: Disney Pixar Movie Inside Out (2015) [9] the abstract scenes

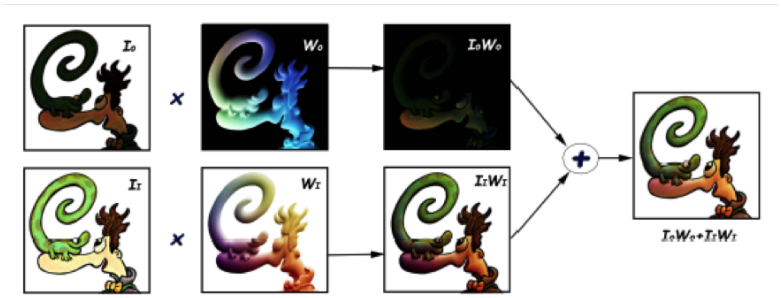
Non-photorealistic rendering in movie production can be used for the whole short as in "Paperman" or "Feast" or a part of the movie as the story required. In 2015 Disney Pixar released an epic featured film "Inside Out" as shown in Figure2.4 in which there's a unique sequence called the "abstract world". In this sequence, the characters experience four different stages: 1. non-objective fragmentation 2. deconstruction 3.two-dimensionalzation 4. non-figurativity in which they gradually lose their 3D forms and eventually turn to 2D shapes. The rendering of this sequence also changed from a photorealistic to a very stylized non-photorealistic painterly look. Base on the 2016 Siggraph talk from Pixar, all the objects in this sequence are 3D and they developed a unique shader just to achieve this 2D look. This approach was successful which makes this abstract sequence visually more appealing and meanwhile it serves the whole story better than a traditional photorealistic render. As more and more animated films are in production now or would be in production soon, an increasing need of NPR rendering in the art style would be predictable.

2.2 NPR Studies in Research

Examples of NPR uses: Liu conducted a reseach in 2015 involving the render of a scene in Chinese ink painting style with reflections on a river, which has a really nice convincing Chinese Ink painting effect. [10] Later in 2016 Du did a research on a NPR charcoal shader which sucessfully achieved a nice charcoal drawing style with reflections on vases. [12] Montesdeoca developed a independent Maya shader plug in and his system achieved good watercolor rendering results. Figure 2.1 is a hedgehog character in watercolor style rendered by his system. [13] Chen [14] conducted a research to create real-time AR NPR video effects of the sort that require visual and temporal coherence, such as water-colorization or mosaics. Lummon [15] presented a watercolor inspired method for the rendering of surfaces to mimics the watercolor process by building up an illuminated scene through the compositing of several layers of semitransparent paint.

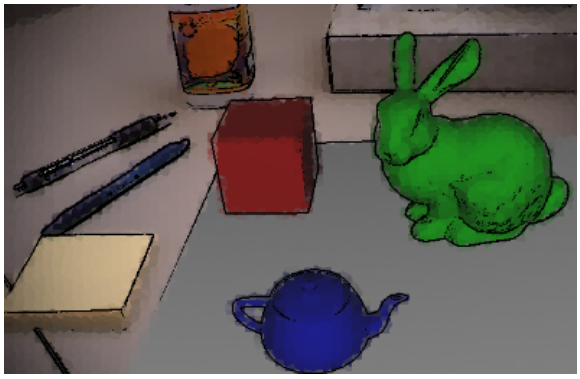
(a) *Chinese Ink Painting Shader by Liu*

(b) *Charcoal shader by Du*

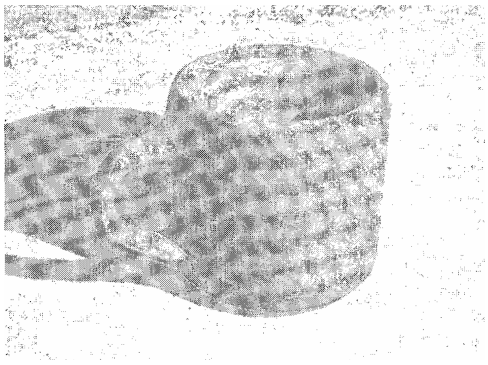


(c) *Barycentric Shader by Alkeman*

(d) *Watercolor Render by Motesdeoca*



(e) *Watercolor Render by Chen*



(f) *Render result by Lum*

Figure 2.5: Previous studies and the results (a) Render by Liu [10] (b) Render by Akleman [11] (c) Render by Du [12] (d) Render by Montesdeoca [13] (e) Render by Chen [14] (f) Render by Lum [15]

A new approach, called Barycentric Shaders as shown in Figure2.5, is developed to simplify shader development through a more intuitive and streamlined process [12] This method has successfully been used in some specific artistic styles and has achieved some promising results in Chinese ink painting look [10] and charcoal drawing look [12] in the computer rendered 3D scenes. A recent study conducted by scholars in Nanyang Technological University presents some advanced results in watercolor style rendering with art-directed control. [13] However, the result is achieved through the real-time Autodesk Maya viewport render system developed. In my research, I focus on achieving the render results offline as in the mainstream film production pipeline and adding the application of watercolor effects to the reflections of the 3D objects with the considerations of global illumination.

3. METHODOLOGY

In this chapter, I discuss the theoretical framework that this research is built upon, followed by the mathematical background of the structures.

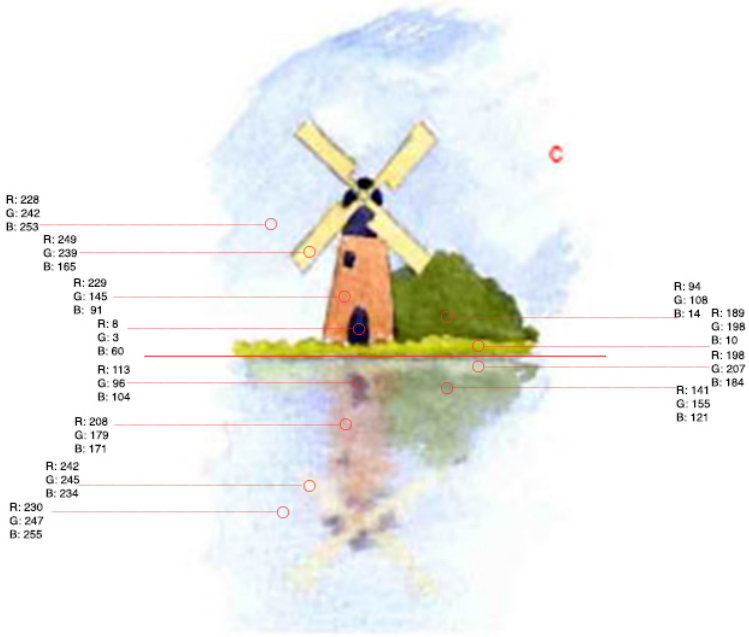


Figure 3.1: Cloudy

3.1 What Is Reflection

Reflection is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated. Common examples include the reflection of light,sound and water waves. Reflection of light is either specular (mirror-like) or diffuse (retaining the energy, but losing the image)

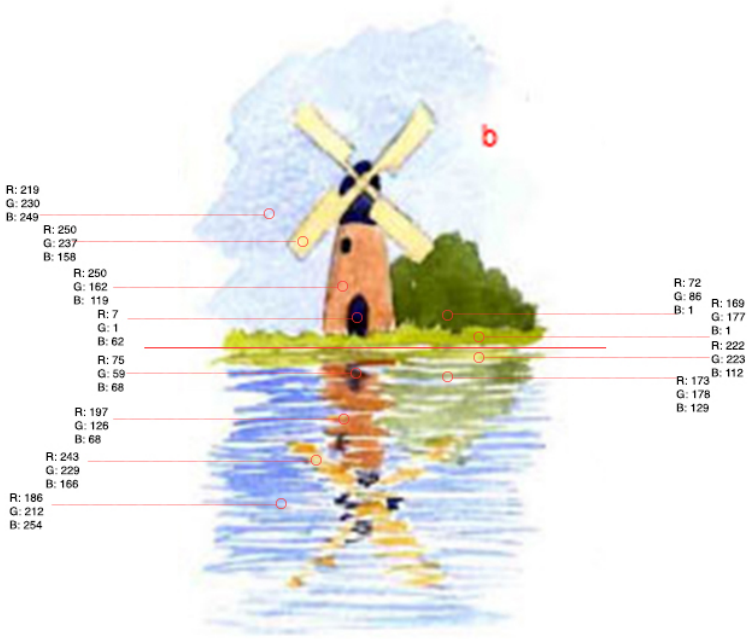


Figure 3.2: Windy

depending on the nature of the interface [11].

3.2 Analysing Reflection Transformations in Watercolor Paintings

In this section, I describe how I analyzed the impact of reflections on colors. I will describe the process using the three sample watercolor paintings.

Figure 3.1 is painted to obtain a cloudy day look. The artist blurred the reflections to obtain a cloudy and foggy effect. Moreover, the artist faded the colors of the reflections compared to the original windmill image. Another important decision by the artist was to create a tranquility effect using a low frequency for the waves in the scene.

Figure 3.2 is painted to obtain a windy day look. The artist created the water surface by two distinctive colors from the sky: blue and white. And the reflection color appears to be darker and slightly more saturated. To achieve a windy effect for the waves, the artist

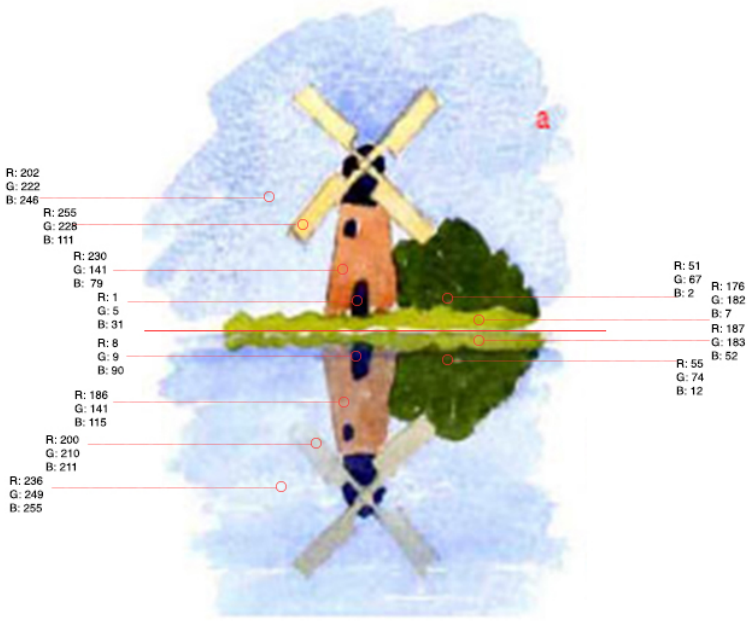


Figure 3.3: Sunny

chooses to put the frequency of the wave high.

Figure 3.3 is painted to obtain a sunny day look. In this case, the artist painted a mirror like water surface. Among the three images I studied, this is the one with minimum distortion due to reflection. Therefore, the water surface looks a lot like a mirror. For a believable sunny day effect, the artist chooses to have a blue tint over the water surface which also effects the colors of the reflections of the windmill and the bushes.

To quantitatively evaluate the effect of reflection, I have taken color samples from pixels that corresponds the original positions and their reflections. I took samples for all three images. the goal is to use these samples to obtain a transformation operation that can map original colors into reflected colors.

For each image, I have sampled six different materials and for each material I have

sampled two pairs of colors, one for the original material and one for its reflection. Each color consists of three channels: Red, Green, and Blue, or simply RGB. As a result for every image, I have obtained a total 12 RGB values. The following lists provides color samples I have taken from each image.

The samples are shown in Figure 3.1.

- 12 samples for each color and its reflection
  - $(228, 242, 253) \rightarrow (230, 247, 255)$
  - $(249, 239, 165) \rightarrow (242, 245, 234)$
  - $(229, 145, 91) \rightarrow (208, 179, 171)$
  - $(8, 3, 60) \rightarrow (113, 96, 104)$
  - $(94, 108, 14) \rightarrow (141, 155, 121)$
  - $(189, 198, 10) \rightarrow (198, 207, 184)$

Samples taken from pixels are shown in Figure 3.2.

- 12 samples for each color and its reflection
  - $(219, 230, 249) \rightarrow (186, 212, 254)$
  - $(250, 237, 158) \rightarrow (243, 229, 166)$
  - $(250, 162, 119) \rightarrow (197, 126, 68)$
  - $(7, 1, 62) \rightarrow (75, 59, 68)$
  - $(72, 86, 1) \rightarrow (173, 178, 129)$
  - $(169, 177, 1) \rightarrow (222, 223, 112)$

Samples taken from pixels are shown in Figure 3.3.

- 12 samples for each color and its reflection
  - $(202, 222, 246) \rightarrow (236, 249, 255)$
  - $(255, 228, 111) \rightarrow (200, 210, 211)$
  - $(230, 141, 79) \rightarrow (186, 141, 115)$
  - $(1, 5, 31) \rightarrow (8, 9, 90)$
  - $(51, 67, 2) \rightarrow (55, 74, 12)$
  - $(176, 182, 7) \rightarrow (187, 183, 52)$

Based on this data, our problem is to find a transformation that minimizes the error in mapping the original colors to reflected colors. Let $\mathbf{c}_{o_i} = (r_{o_i}, b_{o_i}, g_{o_i}, 1)$ and $\mathbf{c}_{r_i} = (r_{r_i}, b_{r_i}, g_{r_i}, 1)$ denote original and reflected colors for material i. Now, let us assume that there exists transformation in the form of a 4×4 matrix, denoted by M then the problem reduces to find an $\mathbf{M}$.

Elements of matrix $\mathbf{M}$ can also be any real number. Allowing negative numbers is crucial to find matrices that provide reasonably close solutions for a given set of data. If the computation results in negative colors, they can be converted to zero for the display. Based on this model, we can define the problem as follows: Given a set of data points that represents color transformations by reflection as follows $\mathbf{c}_{o_i} \rightarrow \mathbf{c}_{r_i}$ find a matrix $\mathbf{M}$ that minimizes the following formula,

$$\sum_{i=0}^{N-1} |\mathbf{c}_{r_i} - \mathbf{M}\mathbf{c}_{o_i}|^2$$

where N is the number of corresponding sample color points obtained from painting and $|\mathbf{c} - \mathbf{c}'| = \sqrt{(r - r')^2 + (g - g')^2 + (b - b')^2}$ is the Euclidean distance between any two colors $\mathbf{c}$ and $\mathbf{c}'$ computed by using L_2-norm.

If we write an equation for each channel, r, g, and b, the problem can be solved by using uni-variate analysis of variance (ANOVA), which will give us a diagonal matrix as a solution [19].Since we have three channels and we tie them to each other by using Euclidean distance, the problem is truly multidimensional. A statistician, Dr. Derya Akleman, applied Multivariate Analysis of Variance (MANOVA) that is used to test a hypothesis on two or more response variables when multiple observations are taken [20]. She provided transformation matrices computed using MANOVA. .

Carl Van Huyck has developed a simple program to visually inspect the impact of transformation matrices. This program simply reflects an image by flipping it horizontally and transforms the colors of pixels based on a transformation matrix. Using his program, it is possible to quickly check the quality of our results based on given matrices.

Figures 3.4b, and 3.4d show emulation of reflections in two watercolor paintings obtained by this process of image reflection and color transformation using Carl Van Huyck's program. Corresponding matrices obtained by MANOVA are given below for emulating reflections in the original images given in Figures 3.4a, and 3.4c.

$$M_a = \begin{pmatrix} +0.37 & +0.52 & +0.12 & 07 \\ -0.13 & +1.05 & +0.12 & 07 \\ +0.19 & -0.05 & +0.87 & 32 \\ +0.00 & +0.00 & +0.00 & 01 \end{pmatrix}$$

$$M_c = \begin{pmatrix} +0.38 & +0.11 & +0.08 & 99 \\ -0.02 & +0.61 & +0.06 & 90 \\ +0.02 & +0.44 & +0.25 & 81 \\ +0.00 & +0.00 & +0.00 & 01 \end{pmatrix}$$

As shown in these examples, using statistical analyses and a proprietary software we can

(a) *Original Painting a.*

(b) *Computed Reflection for a.*

(c) *Original Painting c.*

(d) *Computed Reflection for c.*

Figure 3.4: Emulations of reflection in two watercolor paintings. The original watercolor images are used in permission courtesy of Watercolor artist Marie Perrier.

get very good results for most colors. As it can be seen in these matrices, the color channels can impact each other and some of the parameters of matrices becomes negative numbers. My initial goal was to get similar results using commercial software.

3.3 Function and Control Image

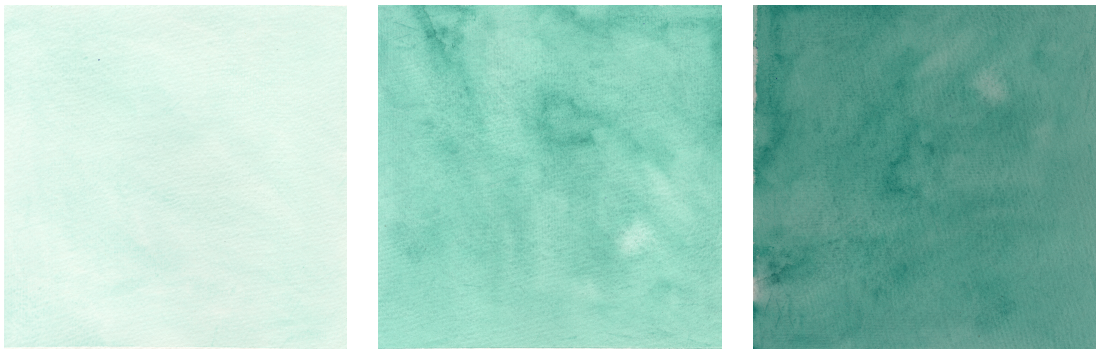
The scene will be constructed in Autodesk Maya and rendered with Mental Ray. The node editor system in Maya could create customized shading networks which provides the maximum flexibilities and possibilities for testing and tailoring shaders without code required. It is very artists-friendly and easy accessing. When creating my shader, I used the charcoal shader that Du created [12] as a foundation of my shader. I only modified some crucial key elements to obtain the watercolor effects.

1. **Barycentric Basis Functions for Watercolor Painting:** The Barycentric function can be given as follows

$$C(u,v) \;=\; \sum_{i=0}^{M} \; B_i(t) \;\; T_i(u,v)$$

   where $C(u,v)$ is rendered color of the point (u,v), $T_i(u,v)$'s are texture images (called control images here in this paper) and t is one of the shading parameters such as diffuse parameter, specular parameter, ambient occlusion or shadow and $B_i(t)$'s are basis functions that satisfy the partition of the unity property [11].

2. **Control Images for Watercolor Paintings:** Hand drawn watercolor textures are created manually. When painting the texture maps, I pay extra attention to the brush strokes, water amount in order to have a consistent look when the maps are applied to the 3D objects. I then scan the maps and transfer them into digital files with an additional editing in Photoshop to ensure the map is seamless and tileable.



(a) (b) (c)

Figure 3.5: Initial set of maps for highlight, midtone and shadow

During the initial tests, there are only three hand drawn watercolor texture maps, which represent highlight, middle tone and shadow within a green tone as shown in Figures 3.5. The test results are shown in Figures 3.6. The hue shifts were achieved by the applying the hue shift node in Maya shading network. The initial idea is to use a basic set of maps and achieve every single color (the hue shift, saturation shift or value shift) by applying the HSV node in Maya. And I was able to achieve a convincing result during the initial tests of a very simple 3D scene of a water drop and a sphere with only one directional light to illuminate the scene. The render results without the reflection look more successful as a painterly render.

I then found that with the HSV node,it is hard to control the exact colors (exact RGB values) that I aim to create as well as time-consuming to do all the blind rendering tests. Based on my previous shading experience in a photo-realistic rendering environment, I found it would be more effective to make small modifications using the HSV node rather than depending on it completely for the control over the diffuse colors of the shader. Therefore, to achieve a better render result for a more believable watercolor painterly style of the 3D scene, in the later tests I created control maps for each major color: yellow, orange,

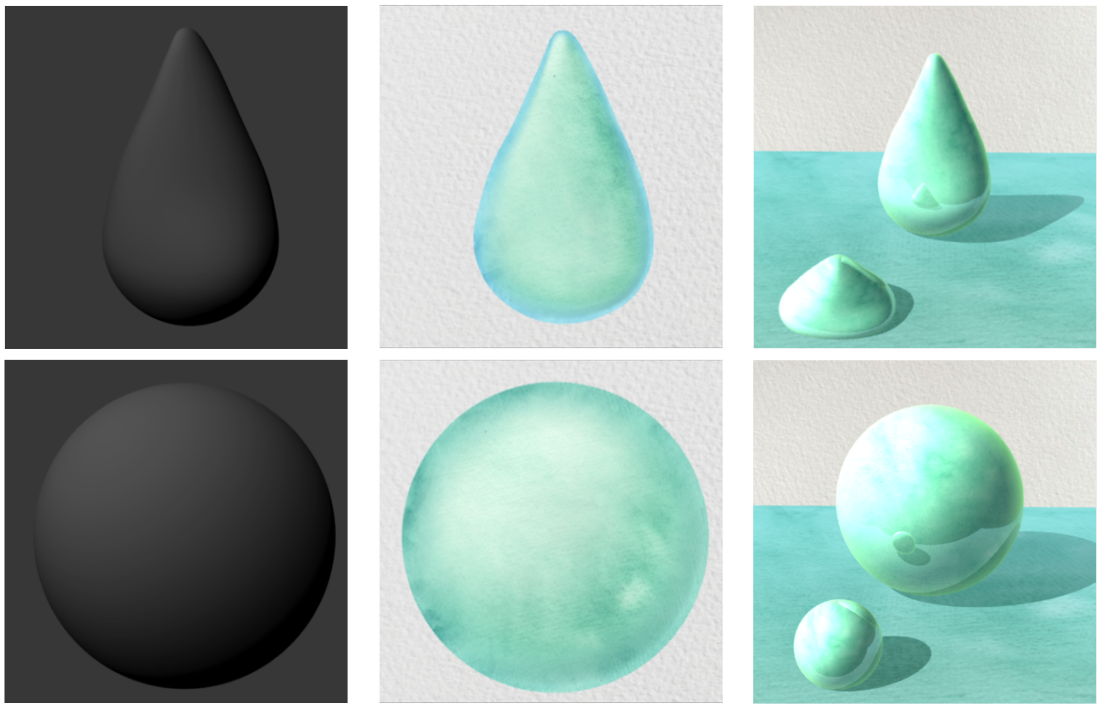


Figure 3.6: The initial reflection testing and watercolor shading renders

green, dark green, navy blue. Each color has three control maps, which are highlights, middle tone and shadows for each color. The render results are showing a more promising look than using a set of maps with a single hue. For a more efficient manner, each color has one hand painted watercolor texture map in middle tone which I then scanned the original painting and edited it in Photoshop to create the highlight map and the shadow map. To avoid a uniformed look, I rotated the highlight map and the shadow map to two different directions as the middle tone map. Therefore, in one color, among the set of three maps, each map has different pattern, which is not repeating. I applied this approach to all 6 pairs (18 individual) maps shown in Figures 3.7.

This set of 18 maps worked fine with the watercolor style rendering for the windmill scenes and could achieve faithful colors of the original watercolor paintings. However,

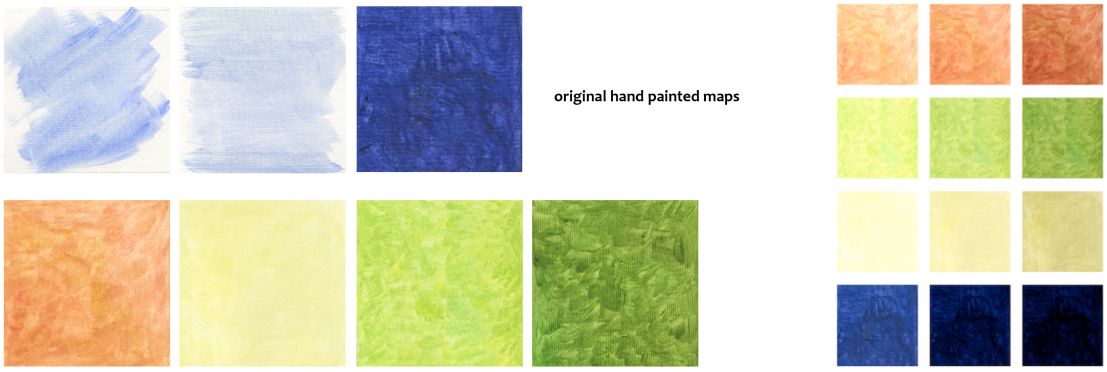


Figure 3.7: Hand painted map set

it could not achieve the faithful colors for the reflections on the lakes as shown in the original three watercolor paintings. As the previous calculation shows, there are negative numbers in the matrix calculated. Therefore, Maya and Mental Ray could not handle these calculations directly nor is there a customized area for a scripting plug in. So it would not be achieve by using the default setting in the commercial 3D software Maya and Mental Ray, unless a customized independent scripting system could be developed. Meanwhile it could work together with Maya and Mental Ray.

If in a situation where no reflection would be conducted, the watercolor shader I currently created could do the job for a 3D scene that rendered with Mental Ray. For a general application, the shifts of the colors for the shader could be achieved by adding a hue shift node in the watercolor-shading network. So the users can choose any other color they want by an easy control for hue. More control maps could be created for a smoother transfer from light to dark when the shader responses to the lights.

3. Watercolor Painting Hierarchy

The shader is created considering the real life order which watercolor use painters when they are creating their paintings. One of the most common techniques used in wa-

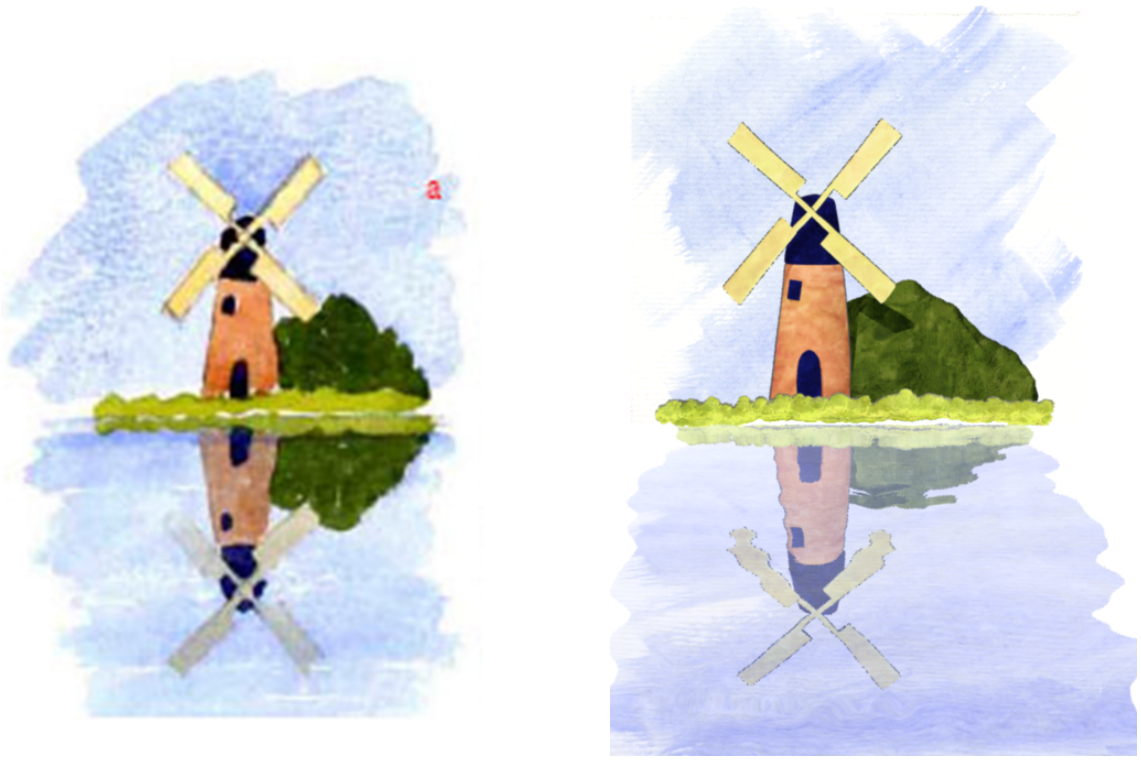
tercolor is the application of thin washes of watered paint to regions of the paper. [15] In Andy Walker's painting as shown in figure (a), the reflections come last, where many artist will use an extra water drops to blur the reflections. Similarly, I use the same hierarchy principle for my watercolor shader parameters.

4. RESULTS

In this chapter, I discuss the CG rendered results that I achieved in this research, followed by the comparison with the targeted original watercolor images. I will analyze the difference and the limitation of current commercial software.

4.1 CG rendered results

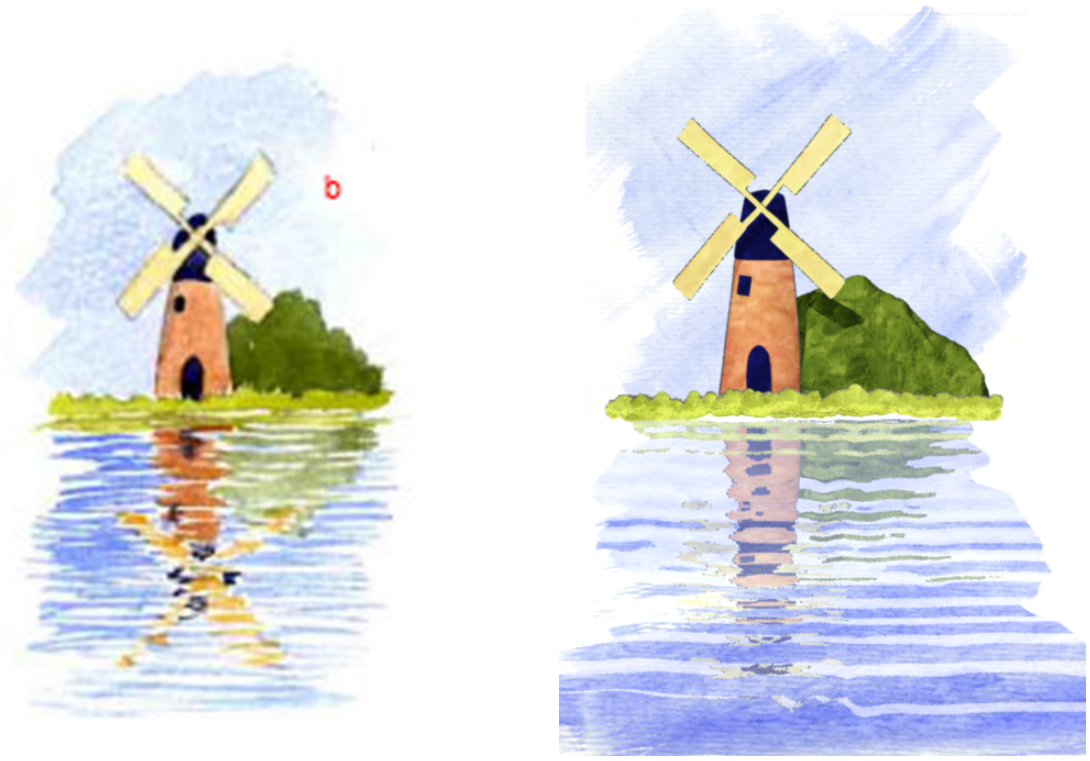
Figures 4.1 4.2 and 4.3 provides the best rendered results from the 3D windmills scene that build in Maya and the rendering engine is Mental Ray.



(a) *Original Painting a.* (b) *My Reflection for a.*

Figure 4.1: Comparison between my result and the original painting a

As you can see in these images, I could not achieved correct colors for reflected regions. As discussed earlier, the reason behind this failure is that there is no perfect solution for artistic reflections. Our best bet comes using a statistical approach to reduce errors. Even in that case, we need 4×4 transformation matrices and some of the elements of transformation matrices should be negative numbers. Unfortunately, the shader development system I chose, Mental Ray, does not support such a transformation without programming.



(a) *Original Painting b.* (b) *My Reflection for b.*

Figure 4.2: Comparison between my result and the original painting b

As clearly to be seen by comparisons provided by Figures 4.1 4.2 and 4.3, I could not

achieved correct colors for reflected regions. As discussed earlier, the reason behind this failure is that there is no perfect solution for artistic reflections. Our best bet comes using a statistical approach to reduce errors. Even in that case, we need 4×4 transformation matrices and some of the elements of transformation matrices should be negative numbers. Unfortunately, mental ray does not support such a transformation without programming.

(a) *Original Painting c.* (b) *My Reflection for c.*

Figure 4.3: Comparison between my result and the original painting c

4.2 Further Discussions of Results

Figure 4.4 provides additional images that demonstrate the effect of the noise for the cloudy scene. In these examples given in Figure 4.4, the windmills scenes are rendered out with only ambient occlusion. I also put some previous render results of the water reflection

tests in Figure 4.4 to show the progress of my study and different look results that I got in the experiments.

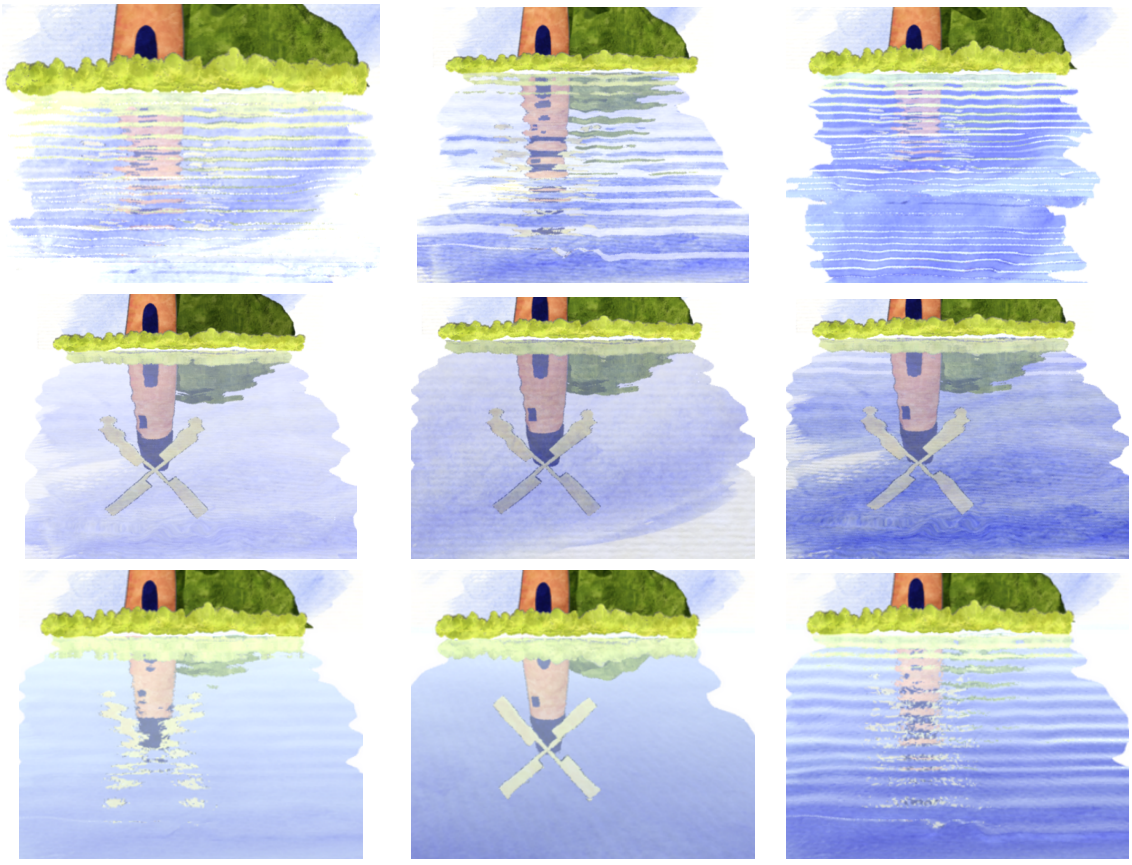


Figure 4.4: Some reflection testing renders

Although, I was able to faithfully recreate the non-reflective part of the paintings in CG and rendered out similar style images. However to have my result and the original paintings side by side, we can see the comparison and differences. The RGB colors are not matching form my result to the original watercolor painting. The pattern of the wave is also lacking the watercolor brush stroke feeling that is presented in the original watercolor

paintings. Therefore, for the current commercial 3D software, the targeted stylized results could not be achieved unless there could be a way to modified the settings on top of the default shading system.

5. CONCLUSION AND FUTURE WORK

The Barycentric shader method provides intuitive art-directed control, and its framework allows the shaders to be included in any rendering pipeline without major changes. [11] In my research, the Barycentric shader would be the ideal method to start from and then with the addition of the customized elements to eventually achieve the stylized watercolor look in 3D. The methodology makes the shader highly controllable as the artist has full access to the diffuse, shadow, reflection, specular and contours. The key part is that all the values could be controlled by texture maps that the artist created. This may be time-consuming but allows the artists to have the freedom and authority over the overall look that they want to achieve.

However, the final rendered result using my watercolor shader did not achieve the original research goal in the aspect of matching the RGB values of the colors of the reflection and also the unique painterly brush strokes that were created in the original watercolor paintings. The two parts could not been recreated in terms of the shading of the water surface in the CG environment rendered by Mental Ray with Maya regardless that a faithful watercolor look is able to created without any reflection elements.

Future work might include the content of a customized tool or plug in which works with Maya and Mental Ray or other commercial 3D softwares for a full control of the RGB colors for the artist to achieve a winder range of the painterly look in a NPR render. Studies of watercolor special effects such as dripping in a CG rendering environment might be included in future studies as well.

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