國立交通大學

多媒體工程研究所

碩 士 論 文

利用直方圖實現一個新的顏色轉移之方法

A Novel Method For Color Transfer Using Histogram

研 究 生：張翔竣

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碩 士 論 文

A Thesis

Submitted to Institute of Multimedia Engineering

College of Computer Science

National Chiao Tung University

in Partial Fulfillment of the Requirements

for the Degree of

Master

in

Computer Science

June 2009

Hsinchu, Taiwan, Republic of China

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摘　要

本篇論文提出了一個利用直方圖作為顏色轉換的新方法。藉由原始影像與參考影像的統計數據分別建立出此兩張影像所屬的直方圖，並於此二直方圖上切割出區段。根據原始影像及參考影像兩者直方圖區段與區段的對應關係，我們將參考影像每個區段的色彩資訊轉移至其對應的原始影像區段，且透過區段間參數的內插解決因為切割區段所造成的色塊破碎問題。藉此我們達到將參考影像的色彩資訊轉移至原始影像上的目的，其結果比現有的顏色轉移方法來的較佳。

A Novel Method For Color Transfer Using Histogram

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ABSTRACT

In this thesis, we propose a novel method for color transfer using histogram. We can construct the histograms individually for both source and reference images based on the statistical analysis of them. After the construction of histograms, we perform segmentation in order to separate the histograms into multiple sections. According to the relationship of corresponding sections between the source and target images, we do color transfer from target to source. At the same time, there will be parameter interpolation between pairs of sections to solve the artifacts along the section boundary. In this way, we can transfer the color information from target image to source image and the result is better than the current methods.

Acknowledgements

First of all, I would like to thank my advisors, Dr. Zen-Chung Shih for their supervision and helps in this work. Then I want to thank all the members in Computer Graphics & Virtual Reality Laboratory for their comments and instructions. I want to dedicate the achievement of this work to my family. Without their support, I couldn't fully on my study.

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Chapter 1
Introduction

1.1 Motivation

Color transfer is a task that a source image copies color characteristics from

a reference image. It is one of the most common topics in image processing. In

fact, with the help of powerful post-processing software, experts can adjust the

image's color characteristic in order to change the image's style but it is complex

and tedious. On the other hand, not everyone is familiar with the professional

software.

Fortunately, digital cameras are very popular nowadays, and people take

photos wherever they like. In this way, there will be a lot of images with different

color characteristics. In this thesis, we propose a method to transfer user desired

color characteristics of an image, called reference image, to the other, called

source image whose color characteristics want to be modified. For transferring

color characteristics of the reference image to source image, Reinhard et al. [2] proposed a simple but effective method using statistical analysis. They use the mean value and standard deviation of both the source and reference images doing shifting and scaling for every source image pixels in each l, α, and β channel.

Although Reinhard's method successfully transfers the reference image's color characteristics to the source image, the transferring algorithm depending only on the mean value and standard deviation for each image makes the final result lose its original feature or obscure. The scaling term according to the deviation ratio breaks the original structure of the source image in the extreme case, for instance, the standard deviation of reference image equals 0.

In our approach, we apply histograms to Reinhard's method and segment it into three sections. Each histogram section has its own mean value and standard deviation. Then we transfer the color characteristics of reference image to the source image based on their corresponding sections. In this way, not only the original feature of source image can be maintained, but also the reference color characteristics can be transferred more matching to the source. During the color transfer between pairs of sections, there will be unnatural artifacts along the section boundary. So we interpolate the mean value and the standard deviation in the same histogram with different sections. In order to solve the extreme case, we

apply a structure control term into the scaling ratio whose concept comes from the HDR linear function. With the enhancement we proposed above, our color transfer algorithm has better results and suitable for all the applications of Reinhard's method.

1.2 Overview

The flow of our proposed method is shown in Figure 1.1. First, user inputs a source image and a reference image. For example, if we want to modify a sunny seascape image with clouds to a dusk feeling, we can provide a nightfall image as the reference.

To enter the core of our algorithm, we have to convert these two images into certain color space. In this thesis, we use $l\,\alpha\,\beta$ color space, an orthogonal color space which is suitable for apply different operations in different color channels with confidence that undesirable cross channel artifacts won't occur.

After color space conversion, construct the histograms in each $l\,\alpha\,\beta$ channels for both source and reference images, and find out the left and right thresholds for each histogram. According to the threshold, we can segment each histogram into three sections, called the left section, the middle section and the right section. In the same color channel, a histogram section of the source image has its corresponding section in the reference image. We will do color transfer from

the reference image to the source image section by section.

When we apply color transfer based on the section correspondence, section parameter interpolation is certainly needed. That means we can't transfer color characteristics only from one section to another, the section will interpolate its parameter with another section which next to it, and then transfer it.

Finally, the color characteristics of reference image with dusk feeling will be transferred to the source image. Then we can get the nightfall seascape image with clouds.
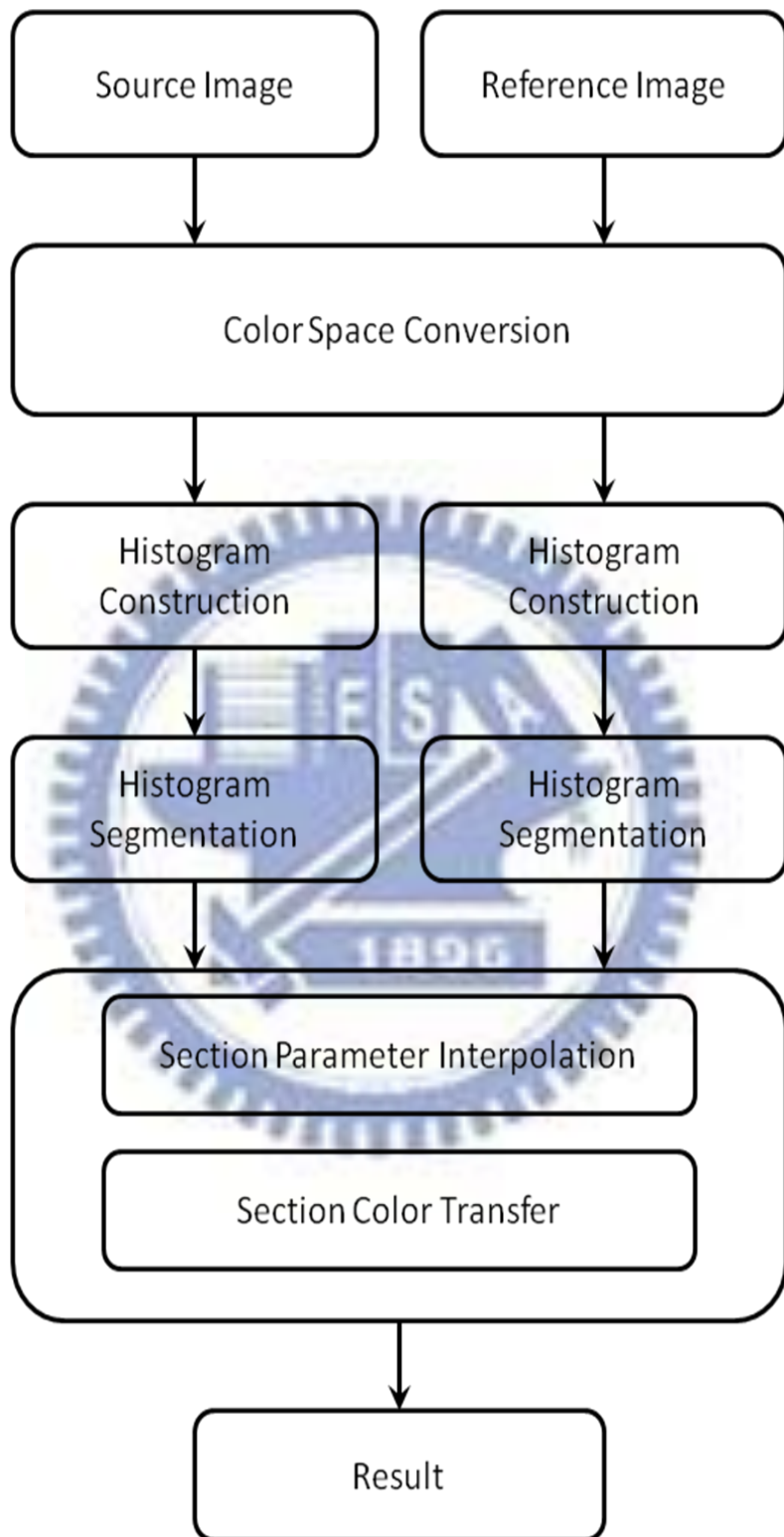
Figure 1.1

The major contributions of this thesis are as follows: First, we apply histogram segmentation and section color characteristics transfer based on Reinhard's method and have a better result. Second, the structure control term which is added to the scaling ratio makes the result maintain the original feature of the source image more correctly. Third, our approach is suitable for current application of Reinhard's theory because of the same concept.

1.3 Thesis Organization

The rest of this thesis is organized as follows: In Chapter 2, we review related works about color transfer and colorization techniques. In Chapter 3, we introduce how we decide the segmentation threshold to do histogram segmentation and section parameter interpolation. Chapter 4 presents the structure control term to maintain the source image structure. The results and implementation are shown in Chapter 5. Finally, conclusions and future works are discussed in Chapter 6.

Chapter 2
Related Works

In this chapter, we review previous researches related to our work. We focus on colorization techniques and color transfer applications.
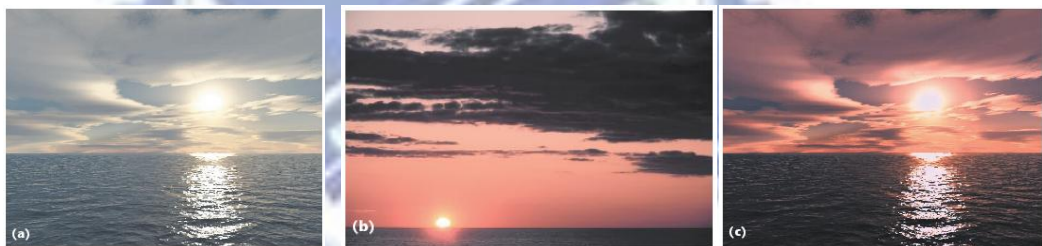

Figure 2.1

The color transferred result by Reinhard's result

Left: The source image

Middle: The reference image

Right: The result

Reinhard et al. [2] describe an automatic system for transferring the color characteristics from one color image to another. This system works by modifying the mean and the standard deviation of colors in the image that matches the

three-dimensional distribution of color values between the images and then transforms the color distribution of the reference image to match the distribution of the source image. Figure 2.1 shows the result image which its color characteristic is transferred from the reference image to the source image.

Welsh et al. [3] colorized a gray image by transferring color from a source, color image, to a destination, gray image. First, each image is converted into the l α β color space. Next, each pixel in the grayscale image arrange in scan-line order and select the best matching sample in the color image using neighborhood statics according to the luminance channel. The chromaticity values (α , β channels) of the best matching pixels are then transferred to the grayscale image by using Reinhard's method to form the final mage. Figure 2.2 shows the results. In general, Welsh's method works well on scenes where the image is divide into distinct luminance clusters. However, their current technique does not work very well with the image of similar luminance.

Figure 2.2

The colorized result by Welsh's method. Left: The source image; Middle: The reference image; Right: The colorized result.

Levin et al. [4] supposed that luminance is related to color. Their method is based on a simple premise: neighboring pixels in space-time that have similar gray levels should also have similar colors. Artists only need to annotate the

image with a few color strokes, and the indicated colors are automatically propagated in both space and time to produce a colorized image or sequence by solving an optimization problem. Figure 2.3 shows a gray image marked by the user's color strokes and the corresponding colorization result.
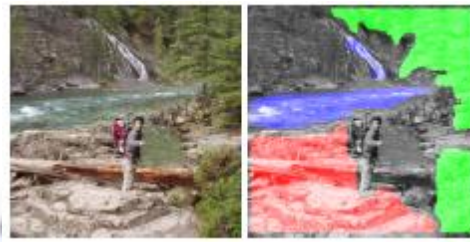

Figure 2.3

The result of Levin's method. Left: The original image and user drawing stroke; Right: The colorized result image

Finding a good match between a pixel and its neighborhood in a grayscale image and a pixel in the reference image is not sufficient for a successful colorization. Pixels with the same luminance value and similar neighborhood statistics may appear in different regions of the reference image, which may have different semantics and different colors. Moreover, it is tedious to scribble on an image with complex scenes. In Irony et al., a method is presented for automatically generating such scribbles from an example image provided by the user.

Irony et al. [5] uses a supervised learning technique to classify in the feature-space and a voting technique to increase the spatial consistency of the colorized image. Next, transfer color only to pixels with high - level of

confidence, and feed the colored pixels as "micro-scribbles" to the optimization algorithm of Levin et al., which produces the final result. This technique assumes that a similar example image is pre-segmented. Otherwise, the task of segmenting the example image itself can be almost as hard as colorizing the input image. Figure 2.4 shows the Irony's method.

(a) Reference image along with a partial segmentation
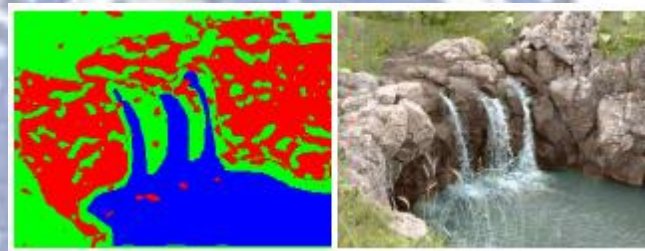
(b) Classification and resulting colorization

Figure 2.4 Irony's method requires an example image with a few user-marked or automatically segmented regions

To supply more user control, an application of Reinhard's algorithm , Wen et al. [6] presented a multiple local color transfer system with a stroke-based user interface. Through their system the user can easily enhance a defect (source) photo by referring to some other good quality (reference) images simply by drawing some strokes. The user draws several strokes on the source and target images to indicate corresponding regions and also the regions that want to preserve. Then the system will perform the multiple local color transfer

automatically. Finally, the defect image can be enhanced. Figure 2.5 shows the process of Wen's method.

(a)   (b)

(c)   (d)
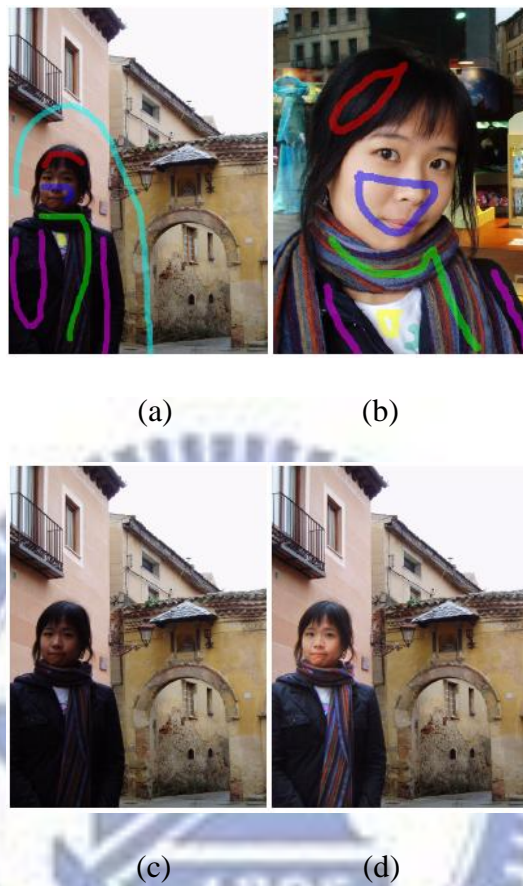
Figure 2.5

(a) Strokes on the source photo. The light blue stroke was drawn for preserving the background; (b)The reference image; (c)The source image; (d)The result

Based on Reinhard's method, all above researches work very well not only on colorization but also on color characteristics transfer. As we mentioned before, the improvement on Reinhard's algorithm by applying histogram to it and adding a structure control term to the scaling ratio can generate better quality results. In this way, all of the methods which are based on Reinhard's algorithm also can be improved

Chapter 3
Histogram Segmentation

In this chapter, we show how to segment the histogram of source and reference images. The selection of threshold that is used to do histogram segmentation is discussed in section 3.1. Section 3.2 introduces the parameter interpolation before we do color transfer and the algorithm of our proposed method.

3.1 Segmentation Threshold

We apply histogram to both of the source image and reference image in each l, α, and β color channel. The horizontal axis of the histogram is the color channel value and the vertical axis is the number of pixels.

In this thesis, we assume that the histogram of each color channel consists of three sections: the *major section*, the *left extreme section* and the *right extreme section*. The major section is a cluster of color channel values that close to the average of the whole channel. The left extreme section and the right extreme section are the clusters of color channel values that far away from the average, which

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represents the border characteristic. Figure 3.1 shows the concept of our histogram.
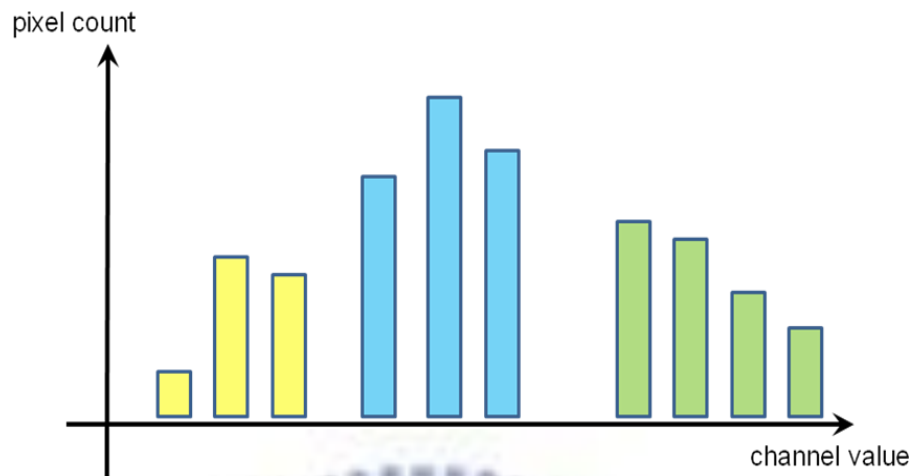

Figure 3.1 Blue buckets comprise the main color section, the left

extreme section is yellow, and the green is the right extreme section.

In the segmentation, we need to find out two thresholds, called the *left* and *right*

thresholds to segment the histogram into three sections. As mentioned before, the

major section collects the color values that close to the mean of the whole channel.

However, the left extreme and right extreme sections collect the color values that

close to the borders. First, we compute the mean value m of the whole color channel,

and m separates the histogram into two temporary sections, the left and right

sections. Then, compute the mean value of these two sections m_L and m_R. The m_L

and m_R are the left and right thresholds of the histogram.

Using m_L and m_R, the whole histogram can be segmented into the three sections.

Color channel values that smaller than the left threshold comprise the extreme left

section. On the other hand, color channel values that larger than the right threshold

constitute the extreme right section. Finally, the remaining color values that between

the left and right threshold form the major section. In this way, we can find out the

major characteristic and the border characteristic of the color channel.

3.2 Parameter Interpolation

Generally, Reinhard et al. do color transfer by using non-segmented histograms.

It means that the entire histogram belongs to one section. They shift the mean value of

the histogram of the source image to that of the target image. Then transform the color

distribution of the histogram of the reference image to match the distribution of the

histogram of the source image according to the ratio of the source image's standard

deviation and the reference image's standard deviation. Based on their algorithm,

color characteristics can be transferred between "pairs of sections" successfully.

In comparison with our method, we segment each histogram into three sections,

represent one major section and two border sections respectively. Transferring color

characteristics based on the section names (main to main, border to border) make the

main color characteristics of the source image matches the main color characteristics

of the reference image and so as the border. In this way, we can get better result than

Reinhard's method.

Although the local color characteristics can be transferred successfully, the

global color characteristics between the sections that in the same image may be

destroyed because of the histogram segmentation. Such artifact which caused by

transferring color characteristics between multiple sections with different mean value

and different standard deviation does not exist in Reinhard's method that using one

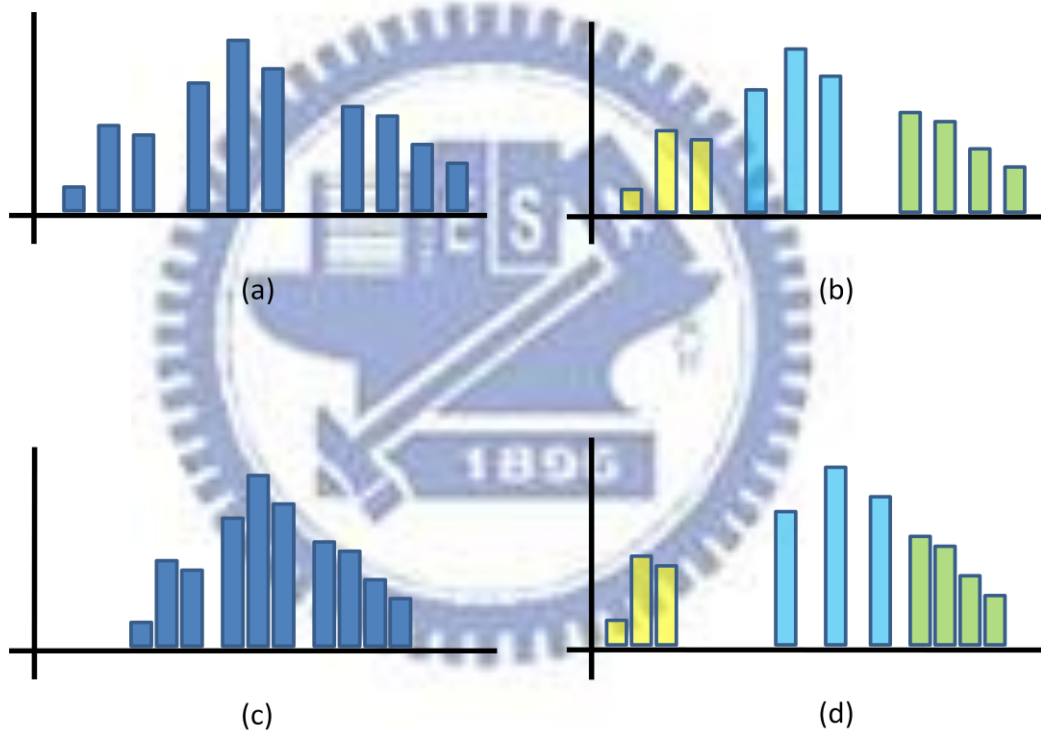section. Figure 3.2 shows the problem of multiple section color transfer.

Figure 3.2 The concept of multiple section color transfer. (a) The source image

without histogram segmentation; (b) Source image with histogram

segmentation; (c) The Reinhard's method after color transfer; (d)Our

method without interpolation after color transfer

We can find that the distance relationship among buckets still maintains certain

ratio after color transfer in Reinhard's method but destroyed in our method.

Figure 3.3 shows the result of our method without parameter interpolation compare to Reinhard's method.
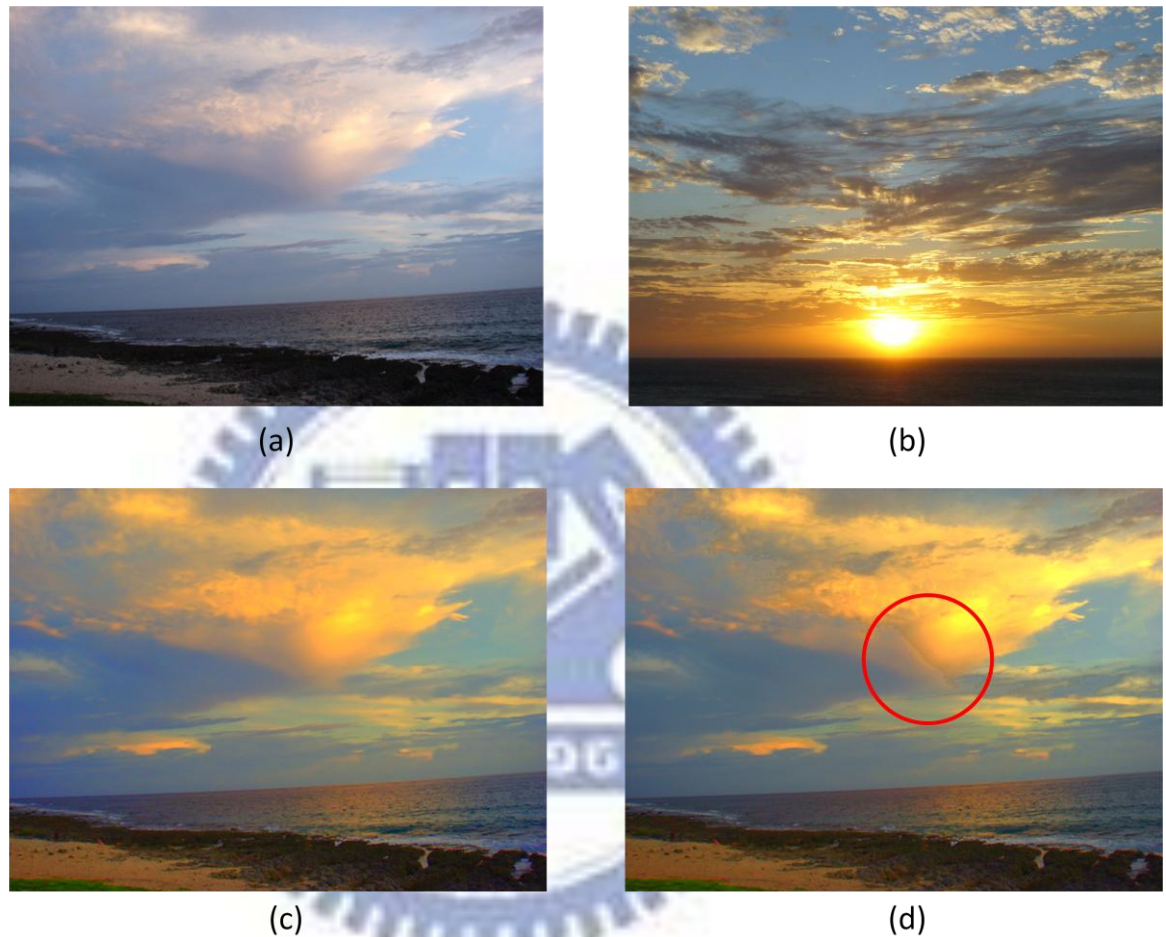

Figure 3.3

The source image (a) and the reference image (b). Reinhard's result (c) does not

have artifacts compare to our multiple section color transfer (d).

To overcome this artifact, we do parameter interpolation before color transfer.

Consider Reinhard's color transfer function for each color channel defined as:

$$p' = r(p - m_s) + m_r \quad , p \in \text{source image} \tag{1},$$

where m_s is the mean value of color channel of the source image, m_r is the mean value of color channel of the reference image, and r is the scaling ratio term that

$$r = \frac{\sigma_r}{\sigma_s} \tag{2},$$

σ is the standard deviation. According to Reinhard's algorithm, each pixel applies Eq.(1) in $l\,\alpha\,\beta$ channels and then gets the final transferred result. In our method, color channel is segmented into three sections, each section has its own mean value and standard deviation. If we apply Eq.(1) directly to these sections, the artifacts will occur. So we do parameter interpolation with respect to the ratio term r and the mean value m_s, m_r between section and sections.

An additional parameter c_m which is called the *middle value* is used to be the threshold when we do parameter interpolation. It is defined by the average of the minimum and maximum in the color channel. Before we apply color transfer to the color channel value which is smaller than the middle value, the scaling ratio and the shifting term in Eq.(1) will be interpolated with the r, m_s, m_r terms that in the major section and the left extreme section, and so as the color channel value that greater than the middle value whose scaling ratio and shifting term will be interpolated with the terms in the major section and the right extreme section.

For the border sections we compute its *section middle values* c_l and c_r which are

the average of the minimum and maximum of that section. The weigh w that we use

to do linear interpolation based on the distance between the color channel value and

the section middle value in the source image. The following algorithm shows the

interpolation process. The shifting term is interpolated by the mean value m in two of

the histogram sections with w and we interpolate the standard deviation σ with the

same w in order to get the scaling ratio r.

Algorithm 1: Parameter Interpolation

1: **for all** color channel value $v < \textit{middle value}$

2:    $d_{vl} = \textbf{distance}\ (v, c_l)$;

3:    $d_{vm} = \textbf{distance}\ (v, c_m)$;

4:    $d_{total} = d_{vl} + d_{vm}$;

5:    $w_{vl} = \textbf{weight}(d_{total}, d_{vl})$;

6:    $w_{vm} = \textbf{weight}(d_{total}, d_{vm})$;

7:    $m_s = \textbf{interpolate}(w_{vl}, w_{vm}, m_{sl}, m_{sm})$;

8:    $m_r = \textbf{interpolate}(w_{vl}, w_{vm}, m_{rl}, m_{rm})$;

9:    $\sigma_s = \textbf{interpolate}(w_{vl}, w_{vm}, \sigma_{sl}, \sigma_{sm})$;

10:   $\sigma_r = \textbf{interpolate}(w_{vl}, w_{vm}, \sigma_{rl}, \sigma_{rm})$;

11:   $r = \dfrac{\sigma_r}{\sigma_s}$;

12: **end for**

,where d_{vl} means the distance from color channel value v to the middle value of *left*

extreme section and m_{sl} means the mean value in the *left extreme section* of the *source*

image. If the color value v larger than the middle value, then all of the parameter in

the left extreme section will be replaced by the right extreme section parameters. After

parameter interpolation, we use the new m_s, m_r and r to do color transfer. Figure 3.4

shows the transferred result after parameter interpolation. The distance weight respect

to the source image, not only remove the artifact between sections but the local color
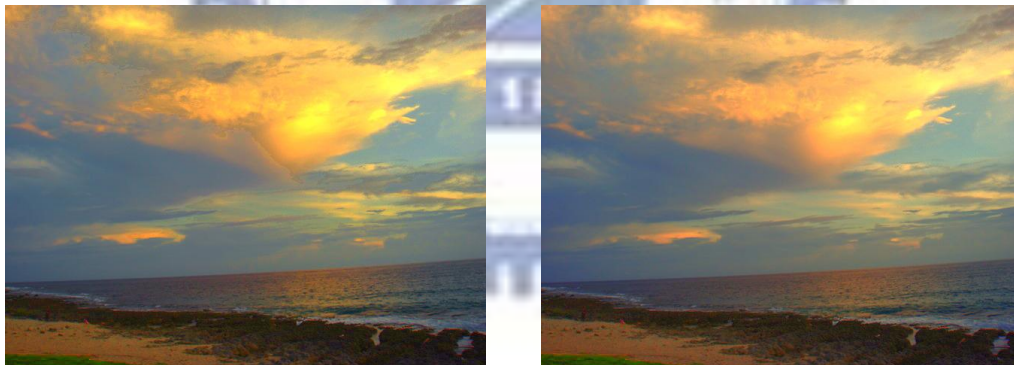
characteristics transferred successfully.

Figure 3.4

Left : Multiple section color transfer without section parameter interpolation;

Right : Multiple section color transfer with section parameter interpolation.

Chapter 4
Structure Control Term

The standard deviation of reference image equals to 0 breaks the structure of

source image in Reinhard's method because of the definition of scaling term based on

the ratio of standard deviation about source and reference images. To solve this

problem, we add a structure control term to the scaling term to maintain the original

structure of source image.

In this chapter, we briefly describe the relation between the scaling term and the

structure control term. The reason that makes the scaling term to zero will be

discussed in section 4.1. And the definition of structure control term will be show in

section 4.2.

4.1 Structure Control Term Motivation

Consider equation 2 in Reinhard's method, no matter what the standard deviation

of source image σ_s is, the scaling term r will be zero if σ_r equals to zero. So, equation

1 can be simplified as:

$$p^{'} = m_r \qquad\qquad (3),$$

in this way, the final color transferred image equals to the pure average color of the

reference image. Figure 4.1 shows an example.

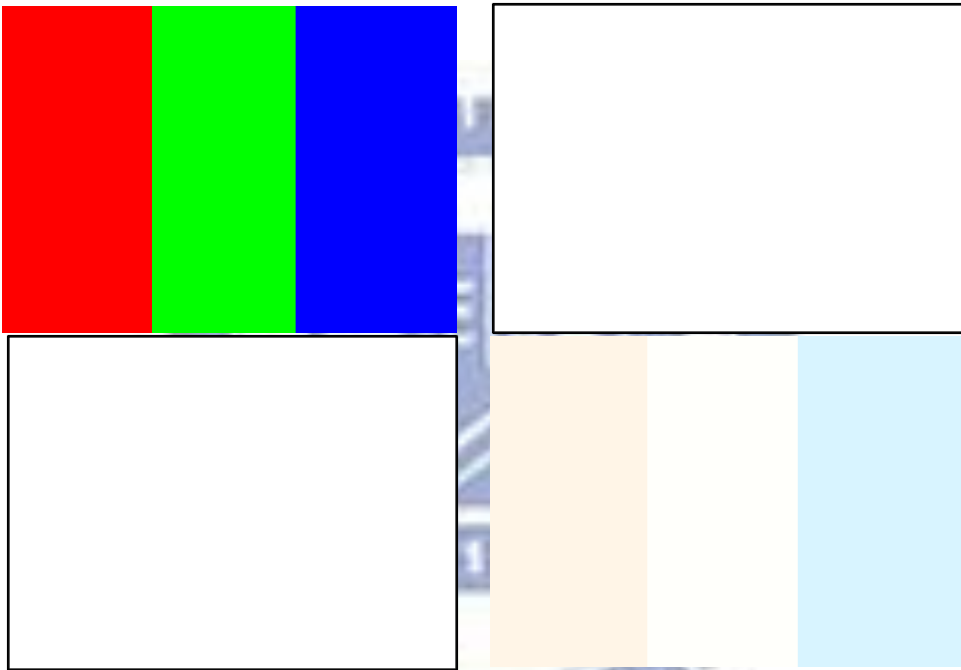Figure 4.1. Left top: The source image; Right top: The

reference image; Left down: Reinhard's method; Right

down: Our method with structure control term

We can find out that if the reference image is a pure color image, and the final

transferred image is a pure color image, too. The standard deviation of a pure color

reference image is zero that breaks the original structure of the source image. In this

way, the final result lost its original structure even though the standard deviation of the source image not equals to zero.

To avoid this phenomenon, we add a structure control term into the scaling term *r* that maintain the source image structure according to the ratio of the standard deviation of both source and reference image. We describe the definition of the structure control term in the following section.

4.2 Structure Control Term Definition

When the standard deviation of reference image closes to zero, we use the structure control term to maintain the structure of source image. On the other hand, if the standard deviation of reference image far away from zero, we use the structure control term to transfer the color characteristics according to the ratio of standard deviation like Reinhard's method. Equation 4 shows our definition of the structure control term.

$$c = \frac{\delta * \sigma_s}{\sigma_r + 1} \qquad (4)$$

The δ is a percentage parameter that for user to control the effect of structure control term on the scaling term. Note that the standard deviation of reference image closes to zero makes the structure control term c closes to $\delta * \sigma_s$. And the bigger the

σ_r, the smaller the c is. This concept is similar to the HDR linear function which is

mentioned by Reinhard et. al [7]. Equation 5 shows the final color transfer function

with the structure control term.

$$p^{'} = (r + c)(p - m_s) + m_r, p \in \text{source image} \quad (5)$$

With the structure control term, we can maintain the original structure of source

image as the right down image of Figure 4.1 does.

Chapter 5
Results

The results of our proposed thesis are presented in this chapter. We compare our method to Reinhard's algorithm. Figure 5.1~5.3 show the results about the scenery. Figure 5.1(a) is the source image: the seascape in the sunny day. Figure 5.1(b) is the reference image: another seascape in the dusk. Figure 5.1(c) shows the Reinhard's result. Figure 5.1(d) is our result.Figure 5.2(a) is the source image: the same as Figure 5.1(a). Figure 5.2(b) is the reference image: a seascape in a cloudy day. Figure 5.2(c) is the Reinhard's result. Figure 5.2(d) shows our result.

(a)   (b)

(c)

(d)

Figure 5.1. (a) The source image; (b) The reference image; (c) Reinhard's result; (d)

Our result.

(a)   (b)

(c)

(d)

Figure 5.2. (a) The source image; (b) The reference image; (c) Reinhard's result;

(d) Our result.

(a)

(b)

(c)

(d)

Figure 5.3. (a) The source image; (b) The reference image; (c) Reinhard's result;

(d) Our result.

According to Figure 5.1 and Figure 5.2, the lightning effect on the cloud that in the source image is blurred and decreased in Reinhard's method. With our histogram segmentation algorithm, we generate better results. Figure 5.3 shows a result that transfer the sunny day to the cloudy day.

Figure 5.4 and 5.5 shows the result about the plant. We not only transfer the flower color but successfully maintain the structure of the flower stamen in Figure 5.4. Compare to Reinhard's method in Figure 5.5, our method transfers the color correctly.

(a)   (b)

(c)

(d)

Figure 5.4. (a) The source image; (b) The reference image; (c) Reinhard's result; (d)

Our result.

(a)

(b)

(c)

(d)

Figure 5.5. (a) The source image; (b) The reference image; (c) Reinhard's result; (d)

Our result.

Chapter 6
Conclusions And Future Work

In this thesis, we proposed a novel method for color characteristics transfer using histograms. The proposed method is composed of three main ideas: histogram segmentation, section interpolation, and the structure control term.

The histogram segmentation and section interpolation can produce good color characteristics transfer results by matching color characteristics according to the histogram sections. With the structure control term, our method successfully maintained the structure of source image even in extreme cases. These contributions make the thesis of color transfer more integrity.

Although our algorithm generates better results than Reinhard's method, there exist improvements. Consider the three color characteristics sections that we used, if we segment the histogram into more than three sections, the quality of the final color characteristics transferred result is an interesting issue. To find a suitable number of

histogram sections for an image becomes one of the future works about our algorithm.

The method that we used to interpolate between histogram sections can also be

improved even that current linear interpolation method is acceptable. Histogram

sections parameter interpolation by using the color distance metric which is similar to

Gooch's method[8] becomes a considerable method when we interpolate histogram

parameters.

Finally, not only the single image color transfer method we improved, but the

application on video contains additional time complexity is our goal in the future.

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