

A Method of Illumination Effect Transfer between Images Using Color Transfer and Gradient Fusion

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Abstract— Illumination plays a crucial role to determine the quality of an image especially in photography. However, illumination alteration is quite difficult to achieve with existing image composition techniques. This paper proposes an unsupervised illumination-transfer approach for altering the illumination effects of an image by transferring illumination effects from another. Our approach consists of three phases. Phase-one layers the target image to three luminosity-variant layers by a series of pre-processing and alpha matting; meanwhile the source image is layered accordingly. Then the layers of the source image are recolored respectively by casting the colors from the corresponding layers of the target image. In phase-two, the recolored source image is edited to seamlessly transit at the boundaries between the layers using gradient fusion technique. Finally, phase-three recolors the fused source image again to produce a similar illuminating image with the target image. Our approach is tested on a number of different scenarios and the experimental results show that our method works well to transfer illumination effects between images.

I. INTRODUCTION

With the prevalence of digital cameras, the needs for image editing and enhancement arise. Digital image composition has recently received much attention for better visual effects in images. The goal of image composition is to combine objects or other image elements from various image sources to create a seamless and realistic image [1]. In traditional scenarios, photographers carefully conceive the color composition of their images to convey desired color themes and artists often use a restricted palette to create expressive work, and can also enhance color contrasts locally to give a better sense of solidity and depth [2-5]. Besides tone and color adjustments, illumination editing is another frequently used operation due to the crucial role of illumination effect in the determination of image quality.

Unfortunately, editing illumination effects of an image is a painful experience. Powerful commercial software, such as Photoshop, does not explicitly support the illumination effect editing. Such software typically adjusts the brightness of the image in a global manner, resulting in unsatisfying and unnatural visual effects. Thus, the users may have to search for a set of effective operations to edit the illumination effect through a large number of trials.

Currently, there are some important works about color alternation in the field of image editing, including color transfer [6, 7], color grading [8, 9] and tone as well as color

theme enhancement [10, 11]. Color transfer is a kind of process of color alteration, which transfers the target image's color statistics to the source image, making the color characteristics of the source image accord with those of the target one [12]. Applications of color transfer are very effective in changing the image mode and enhancing the quality of images. Nevertheless, the domains of color transfer or recoloring methods are limited because it might produce unnatural results when the illumination of source image and target image is quite different. To our best knowledge, there are few researches concerning illumination editing when dealing with image color transfer.

In this paper, we present an image-based approach to transfer illumination effects from the target image to the source image. Our idea is illustrated in Fig. 1. The approach consists of three phases. In phase-one, we segment the target image into several luminosity layers through a series of pre-processing and alpha matting to emphasize the luminosity changes of the image illumination. Accordingly, we layer the source image and transfer color characteristics of each layer from the target image to the corresponding layer of the source image. In general, the direct layer-based color transfer causes excessive color-inconsistency along the boundaries of layers. To resolve the problem of color discontinuity, phase-two edits the color of source image by dividing the source image to equal-size patches and performing gradient fusion [13] in patches. After that, the color-inconsistency artifact is reduced while the luminosity contrasts between layers are preserved. Finally, phase-three recolors the luminosity template derived from the previous phase by transferring the global color characteristics of the target image to it. Note that our approach adopts recoloring method [8, 9] twice, one is in phase-one within the segmented layer, the other one is in phase-three for the whole image. With our approach, users can automatically re-illuminate their photographs according to example images with similar scene, reducing the amount of hand-made artifacts.

The rest of the paper is organized as follows: A review of related studies is briefly described in Section II. In Section III, we describe the framework and technical details of our proposed approach. Evaluations of the proposed approach are summarized in Section IV. Finally, we conclude the paper in Section V.

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Fig. 1 Illumination transfer example. The source image on the top is re-illuminated to the target image on the right-bottom, the result is showed on the bottom.

II. RELATED WORK

Digital image composition techniques are used to assemble existing image elements to create a seamless and convincing image. There have been many applications of image composition, such as image quality enhancement, image tone/theme enhancement, rapid prototyping design, etc. Among these applications, image quality enhancement and tone/theme enhancement are two most prevalent applications in our daily life. Color transfer techniques are typically used to realize the aforesaid enhancements.

A. Color Transfer

Color transfer algorithms aim to apply color characteristics including a color palette, tone or theme, from one image to another [5]. Reinhard et al. proposed the first popular color transfer method [6] which matches the mean and variance of the target image to the source image. The transfer of color statistics is performed separately on each channel in $l\alpha\beta$ color space [14]. Then their method has been extended to sequences in [15] and been further applied to video colorization in [16]. There are some researches considering possible dependence between channels. For instance, Ref. [17, 18] transfers the covariance information by aligning the principal component axes; Ref. [12] proposes an ellipsoid mapping scheme which extends Reinhard et al.'s work to correlated RGB color space. However, these color transfer techniques are limited to affine transformations of the color space. Thus some approaches to the non-linear mapping are proposed. A simple approach [19] is proposed to perform a histogram specification on the three color channels independently. Ref. [20] proposes a more complex mapping to deform tessellation meshes in the color space to fit to the 3D histogram of a uniform distribution.

Moreover, Pitié et al. [8, 9] proposed iterative color distribution transfer. This approach relies on applying a sequence of simple conversions with respect to randomly projected marginal color distributions instead of employing any explicit mapping function of the global color distribution. Specifically, the process of color transfer is to find a one-to-one color mapping for each pixel in the original image. To realize this process, the author tried to find a mapping to transform the source color probability density function (pdf) f into a new color pdf which can match the pdf g in the target image, that is:

$$t(f) = g. \quad (1)$$

It treats the colors of an image as a distribution in a high dimensional space, and repeatedly projects this high dimensional distribution into a series of random 1D marginal distribution using the Radon Transform. The color distribution of the target image is converted to that of the source image by repeatedly mapping its 1D marginal distribution to those of the source image until convergence.

Apparently, most color transfer algorithms are concerned about the direct position-unrelated color transferring. Hence previous color transfer algorithms would be powerless when they try to meet the requirements depicted by Fig. 1. For this reason, we propose our approach. However, position-correlated methods would produce sharp color-inconsistency. To resolve this problem, we adopt gradient fusion technique.

B. Gradient Fusion

There have been many powerful approaches [21, 22] for seamless image composition. In this paper, we incorporate a simple gradient fusion method [13] proposed by Pérez et al. to our approach to modify the artifacts derived from the position-related color transfer method. The algorithm works by solving a set of Poisson equations that enforce the preservation of image gradient inside the inserted object and the pixel values along the boundaries. In this way, the color-inconsistency on the boundary is eliminated.

III. PROPOSED APPROACH

We describe our approach which incorporates the position-correlated color-transfer techniques and gradient fusion method to achieve image-based illumination composition in the following section.

A. Overview of Our Approach

The major difference between our work and other existing image composition methods is that we are concerned with position-related illumination transfer effect between images. Generally, the task of the proposed approach can be divided into three phases. As depicted in Fig. 2, each phase contains some critical components. For phase-one, once a target image and a source image are submitted to the system, the system first segments the illumination layers of the target image and thus generates a *Matting Mask* which restricts the process of layer-based color transfer later on. After transferring colors

within each layer, the system outputs an illumination framework for the following phases. Next, phase-two divides the illumination framework into patches and enforces the preservation of the image gradients to eliminate the color-inconsistency caused by the layer-based color transfer. The luminosity template obtained in phase-two is then recolored globally in the phase-three and we obtain the image which has the similar illumination to the target image. The important notations for our approach have been presented in Table I.

B. Phase One: Illumination Layer Model

In our approach, we use I_o and I_t to denote the source image and the target image respectively. I_o is the image to be illuminated and I_t is the image used as the example.

Pre-processing

The pre-processing of I_t contains following three steps:

First, we divide I_t into n square sections by 30*30 pixels, denoted by $S_1 \dots S_n$. Assuming the pixel at position (i, j) in S_m ($1 \leq m \leq n$) is defined as $P_{i,j}^m$, where $1 \leq i \leq 30$ and $1 \leq j \leq 30$. Thus we have:

$$\begin{aligned} P_{\min}^m &= \min(P_{1,1}^m \dots P_{1,30}^m \dots P_{30,1}^m \dots P_{30,30}^m), \\ P_{\max}^m &= \max(P_{1,1}^m \dots P_{1,30}^m \dots P_{30,1}^m \dots P_{30,30}^m). \end{aligned} \quad (2)$$

Then I_t is converted to a gray-level image denoted by $I_{t,\text{gray}}$ and is normalized each pixel within the section of $I_{t,\text{gray}}$. The max-normalized $I_{t,\text{gray}}$ and min-normalized $I_{t,\text{gray}}$, denoted by I_t^{\max} and I_t^{\min} respectively, are constructed by replacing the values of pixels in each section with their maximum and minimum computed by Eq. (2). Furthermore, we extend I_t^{\max} to the 3-channel image denoted by I_{t3}^{\max} and I_t^{\min} to the 3-channel image denoted by I_{t3}^{\min} .

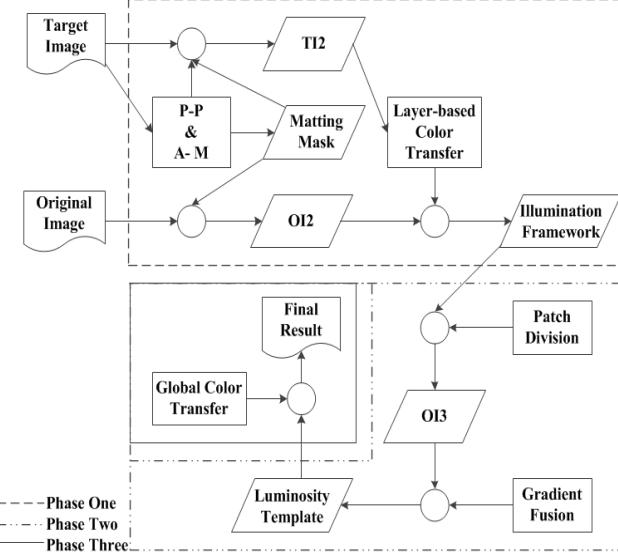


Fig. 2 Workflow of our approach. The proposed approach consists of three phases, and each phase contains some critical components. Note: The parallelograms (TI2, OI2 and OI3) denote the intermediates and the circles denote the collaborations.

TABLE I
NOTATIONS FOR OUR APPROACH

Symbol	Meaning
I_o	Source image.
I_t	Target image.
$I_{t,\text{gray}}$	Gray level image of I_t .
S_m ($m = 1, \dots, n$)	I_t is divided into n sections
$P_{i,j}^m$	Pixel in S_m ($1 \leq i \leq 30, 1 \leq j \leq 30$)
I_t^{\max}	max-normalized $I_{t,\text{gray}}$
I_t^{\min}	min-normalized $I_{t,\text{gray}}$
I_{t3}^{\max}	A 3-channel image extended from I_t^{\max}
I_{t3}^{\min}	A 3-channel image extended from I_t^{\min}
RL	The layer with the highest illumination intensity in I_t
YL	The layer with less illumination intensity in I_t
GL	The layer with the least illumination intensity in I_t
I_f	Illumination framework
I_g	Global-recolored image of I_o for I_t
I_{l-t}	Luminosity template

Alpha Matting

We employ alpha matting to segment the image. In our approach, the inputs to alpha matting are the image pair of I_t and I_{t3}^{\max} and the image pair of I_t and I_{t3}^{\min} . Then it outputs *Matting Mask* as illustrated in Fig. 3: the red layer (*RL*) represents the layer with the highest illumination intensity in I_t while the yellow layer (*YL*) has less illumination intensity and the green layer (*GL*) has the least illumination. Notably, *RL* marks the matting result of the input pair of I_t and I_{t3}^{\max} while *YL* marks the matting result of the input pair of I_t and I_{t3}^{\max} . Furthermore, I_o is arranged in layers according to *Matting Mask*.

Layer-based Color Transfer

The three layers in I_o are recolored respectively using the colors of the corresponding layers in I_t . The recoloring result is an illumination framework (I_f) which is presented as Fig. 5 (a). We summarize the algorithm for this step as follows:

Algorithm 1

Inputs:

- I_t : Target image.
- I_o : Source image.

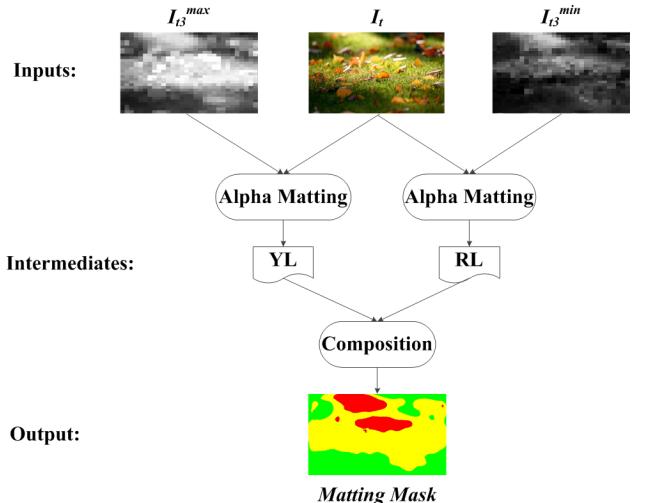


Fig. 3 Workflow of *Matting Mask* generation. The example image is the target image used in Fig. 1.

- *Matting Mask* marked by L_i ($i = 1$: RL, $i = 2$: YL, $i = 3$: GL).

Output:

- I_f : Luminosity framework.

Processing:

- 1) Initialize: $k \leftarrow 1$.
- 2) Iterate until k equals to 3.
 - 2.1) Map the 1D marginal distributions of L_i in I_t to that in I_o until convergence.
 - 2.2) Increase k by 1.

C. Phase Two: Gradient Fusion

After the layer-based color transfer, the illumination framework is color-inconsistent along the layers' boundaries. Inspired by [13], we use their approach to adjust the image color and Fig. 5 (b) shows one example result. First we divide the illumination framework I_f and the global-recolored image I_g into the same equal-size patches. In order to reserve the information of source image as much as possible, we divide I_g into 5×5 patches. Then the global-recolored patches are added to corresponding regions in illumination framework as inserted objects. By solving a set of Poisson equations in patches, the fusion result enforces the preservation of image gradient inside the inserted patches and the pixel values along the boundaries.

Gradient fusion is a guided interpolation method which can be used to eliminate the color-inconsistency between the neighboring regions. As illustrated in Fig. 4, we define the following notation:

- S is the image definition domain (parts of I_f in our case).
- Ω is a closed subset of S (a patch of I_f in our case) with boundary $\partial\Omega$.
- f^* is a known scalar function defined over S minus the interior of Ω .
- f is an unknown scalar function defined over the interior of Ω .
- v is a vector field defined over Ω .
- For each pixel p in S , N_p is the set of its 4-connected neighbors which are in S . f_p is the value of f at p . $\langle p, q \rangle$ is the pixel pair with $q \in N_p$.
- The boundary of Ω is defined as $\partial\Omega = \{p \in S \setminus \Omega : N_p \cap \Omega \neq \emptyset\}$.

Our goal is to interpolate I_g to I_f by patches and numerically compute the set of intensities $f|_{\Omega} = \{f_p, p \in \Omega\}$.

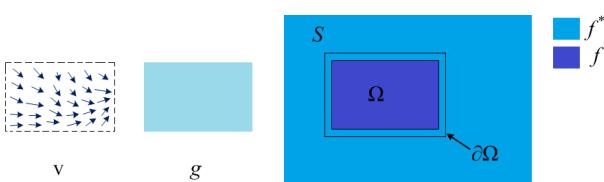


Fig. 4 Guided interpolation notations. Unknown function f interpolates in domain Ω the destination function f^* , under guidance of vector field v , which is the gradient field of a source function g of a patch of I_g .

The interpolate f of f^* over Ω is defined as the solution of the following minimization problem:

$$\min_{f|\Omega} \sum_{\langle p,q \rangle \cap \Omega \neq \emptyset} (f_p - f_q - v_{pq})^2, \text{ with } f_p = f_p^*, \text{ for all } p \in \partial\Omega, \quad (3)$$

where v_{pq} is the projection of $v(\frac{p+q}{2})$ on the oriented edge $[p, q]$, i.e., $v_{pq} = v(\frac{p+q}{2}) \cdot \vec{pq}$. Its solution satisfies the following simultaneous linear equations:

$$\text{for all } p \in \Omega, |N_p| f_p - \sum_{q \in N_p \cap \Omega} f_q = \sum_{q \in N_p \cap \Omega} f_q^* + \sum_{q \in N_p} v_{pq}. \quad (4)$$

Specifically, the basic choice for the guidance field v is a gradient field taken directly from a source image. Denoting by g this source image, the interpolation is performed under the guidance of

$$v = \nabla g, \quad (4)$$

As for the numerical implementation, the continuous specification (5) translates into

$$\text{for all } \langle p, q \rangle, v_{pq} = g_p - g_q, \quad (5)$$

which is to be plugged into (4).

The algorithm of this step is presented as follows:

Algorithm 2

Inputs:

- P_k ($k = 1 \dots 25$): patches of I_g .
- I_f

Output:

- I_{l-t} : Luminosity template.

Processing:

- 1) Initialize: $k = 1$;
- 2) Iterate until k equals to 26.
 - 2.1) Iterate until pixels in Ω of P_k are traversed.
 - 2.1.1) Specify N_p and compute $\sum_{q \in N_p \cap \Omega} f_q^*$.
 - 2.1.2) Construct the guidance field.
 - 2.1.3) Travel to the adjacent pixel.
 - 2.2) Construct the matrix by Eq. (4).
 - 2.3) Solve the matrix.
 - 2.4) Increase k by 1.



(a) Illumination Framework



(b) Luminosity Template

Fig. 5 Illumination framework (I_f) and luminosity template (I_{l-t}) example. I_f (a) and I_{l-t} (b) match the scenario illustrated in Fig. 1.

D. Phase Three: Luminosity Template Recoloring

Empirically, I_{l-t} preserves most luminosity information but loses color characteristics through gradient fusion. By applying recoloring to the image I_{l-t} , we transfer the color characteristics of I_t to I_{l-t} , finally finish the task of modifying I_o to be the image which has the similar illumination and color with the target image.

IV. EXPERIMENTAL RESULTS

The proposed illumination transfer technique has been tested on a number of different scenarios. The results are presented in Fig. 6 and Fig. 7. In the experiments, we choose four groups of images. They are selected by two category partition criteria: natural illumination or artificial illumination, distant view or close view. The 1st group is the still life under candle light; the 2nd group is the skyline under sunlight; the 3rd group is sea of clouds under sunlight and the 4th group is the lawn under sunlight.

In HSV color space, channel V reflects the luminosity of an image. Therefore we use the L1 norm and standard deviation of each corresponding pixel pair in channel V between target image and re-illumination result image as evaluation measurements. Small L1 norm and standard deviation mean that the two images are more similar. We compare the results of our approach with the results of recoloring technique [8, 9] in both visual effect and difference measurements. Fig. 6 shows the comparisons in visual effect and Table II shows the results comparison in the sum of L1 norm difference and the sum of standard deviation difference. We can tell from the Fig. 6 that the results of our method can reserve more illumination characteristic than recoloring method. The same conclusion can be drawn from Table II. Compared with the pure recoloring result, our method is more close to the target image in pixel level.

V. CONCLUSIONS

This paper proposes a method for illumination transfer between images. The method is based on an illumination layer model which layers the illumination region in an image and transfers the color statistics to reconstruct the illumination effects. Then gradient fusion is employed to eliminate the color-inconsistency along the boundaries of the layers. The experimental results demonstrate that our method can achieve illumination transfer on the base of color transfer. However, our approach is position-related; hence it may fail when the source image and target image differ too much.

TABLE II
DIFFERENCE EVALUATION MEASUREMENT AND COMPARISONS

Group	Sum of L1 Norm		Sum of Standard Deviation	
	Recoloring	Our method	Recoloring	Our method
1 st	1.0414e+04	7.171e+03	75.8	49.8
2 nd	1.0716e+04	1.5377e+04	75.8	53.4
3 rd	1.7917e+04	1.5221e+04	74.4	64.1
4 th	1.8291e+05	1.2523e+05	284.1	202.5

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Fig. 6 Results of illumination transfer and comparisons with recoloring method [8,9]