

LETTER

A New Face Relighting Method Based on Edge-Preserving Filter

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SUMMARY We propose a new face relighting method using an illumination template generated from a single reference portrait. First, the reference is wrapped according to the shape of the target. Second, we employ a new spatially variant edge-preserving smoothing filter to remove the facial identity and texture details of the wrapped reference, and obtain the illumination template. Finally, we relight the target with the template in CIELAB color space. Experiments show the effectiveness of our method for both grayscale and color faces taken from different databases, and the comparisons with previous works demonstrate a better relighting effect produced by our method.

key words: face relighting, illumination template, illumination transfer, edge-preserving smoothing

1. Introduction

Good lighting is essential to a good portrait. However, mastering the skill of lighting is not an easy task for the professional photographer or artist, let alone the common user. It would be fascinating to produce lighting effects for the portrait according to the user's desire, and it may lead to many useful applications in face image processing [1]. Therefore, face relighting (or face illumination transfer) has attracted growing research attention in the computer graphics and computer vision community.

Many methods have been proposed for face relighting, such as quotient-image-based methods [16] and morphable-model-based methods [14]. However, these methods require a pair of photographs (one with normal lighting and the other with artistic lighting) [16] or three-dimensional geometric information of the face [14], which seems difficult to satisfy in daily-life application.

There has been increasing focus on single-face relighting methods [7], [9], [10], [15]. Li et al. decomposed portraits using the logarithm total variation, and replaced the illumination-dependent component of the target with that of the reference [9]. Guo and Sim transferred large changes of gradient in the lighting layer of the reference to the target through Poisson editing [2]. Shen et al. employed intrinsic image decomposition [15] for relighting. Chen et al. used an adaptive edge-preserving filter and guided filter to transfer illumination [7].

The above methods have similar workflows. They pre-

serve the illumination of the reference in the lighting layer while discarding the unwanted detail layer. Then, the lighting layer of the target is blended or replaced with that of the reference. Our method is similar to that of Shen et al. [7], since both employ an edge-preserving filter. However, [7] relights faces by lighting layers blending, while our method using an illumination template, which can better transfer the subtle lighting details of the reference.

Recently, researchers have proposed some methods to obtain illumination templates. Jin et al. extracted Haar-like local lighting contrast features from predefined facial areas, and learned the template from artistic and daily portraits using a log-linear model [8]. However, since these templates are learned for lighting-style classification and assessment, we could not use them directly for relighting. Chen et al. collected portrait images to construct a database of templates hand-drawn by artists [10]. They provide two schemes for relighting. One is to directly select the hand-drawn template, and the other is to match the user-provided reference to the closest template using the face illumination descriptor. However, the method employed by [10] may fail to transfer the subtle lighting details of the reference, since they restricted the hand-drawn templates to commonly used lighting situations. Therefore, we believe that directly generating the template from the reference could achieve a better relighting effect.

In this paper, we propose a face relighting method based on the illumination template, which could be effectively generated from a single reference portrait using a modified edge-preserving smoothing filter, as shown in Fig. 1. We locate facial landmarks using an active shape model (ASM) [6], and wrap the reference to the target through multilevel free-form deformation (MFFD) [5]. We then generate the illumination template using an edge-preserving filter based on the weighted least square (WLS) framework [4]. To better preserve the lighting information

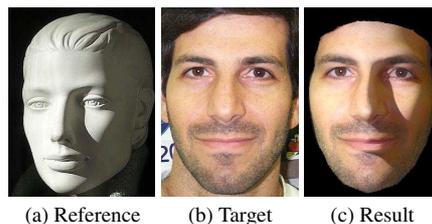


Fig. 1 (a) is the reference; (b) is the target portrait taken from Caltech face database [13]; (c) is the relighting result produced by our method.

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and remove the unwanted identity and texture details, we extend the original WLS filter [4] to that with a spatially variant parameter according to the degree of smoothness of the corresponding region. Finally, we relight the target portrait using the template in CIELAB color space.

We have experimented on the YaleB Extended [12], Lifespan [11] and Caltech [13] face databases, and the results illustrate the effectiveness and reliability of our method for both grayscale and color faces. Comparisons with previous methods [9], [10], [16] show our method produces a relighting effect that is more consistent with the target portrait.

2. Framework of Face Relighting Method

The goal of our method is to generate an illumination template from a single reference portrait for face relighting.

As illustrated in Fig. 2, our relighting framework can be summarized as three steps.

1. Locate facial landmarks, and wrap the reference according to the shape of the target.
2. Generate the illumination template from the wrapped reference using a spatially variant edge-preserving smoothing filter.
3. Relight the target in CIELAB color space with the illumination template.

The details of the three steps are discussed below.

2.1 Feature Extraction and Face Wrapping

To generate an illumination template that matches the facial structure of the target well, the shape of the reference should be aligned to that of the target. We use ASM [6] to locate 64 landmarks of the facial components (such as eyes, nose and mouth) of both faces, and wrap the reference through MFFD [5]. Note that, when the landmarks fail to be accurately located, we would modify their positions in an interactive way.

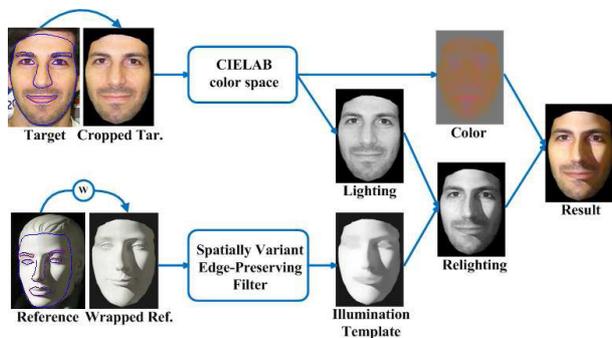


Fig. 2 Our face relighting framework. Step 1: Wrapping the reference according to the shape of the target. Step 2: Generation of an illumination template using a spatially variant edge-preserving filter. Step 3: Relighting the target in CIELAB color space using the illumination template.

2.2 Spatially Variant Edge-Preserving Smoothing

Generation of the illumination template is the key process in our relighting method. The goal is to extract the lighting information from the wrapped reference while removing the facial identity, texture details and small lighting variant. Edge-preserving filtering is suitable for the task, and it has been widely used in many related problems [4], [17].

In our method, the illumination template is generated using the edge-preserving operator based on a WLS framework. The reason is twofold. First, the WLS filter is effective for multi-scale detail manipulation [4]. Second, other explicit filters, such as the bilateral filter [17] and guided filter [18], tend to produce halos near some edges, while the WLS filter does not [4], [18]. To obtain an inhomogeneous smooth effect in different facial regions, we propose a WLS filter with spatially variant smoothing.

For our WLS filter, the output is the relighting template p , the input is the luminance channel l of the wrapped reference, and the guided image L is the logarithm of l . The illumination template is obtained by minimizing the following quadratic energy functional:

$$p = \underset{p}{\operatorname{argmin}} \left\{ \sum_{\mathbf{x}} (p(\mathbf{x}) - l(\mathbf{x}))^2 + \sum_{\mathbf{x}} h(\nabla p, \nabla L) \right\} \quad (1)$$

The first term of Eq. (1) is the data term, which preserves the similarity between the template p and the luminance channel l of the reference. The smaller the data term is, the more illustration information and facial details are retained in the template.

$$h(\nabla p, \nabla L) = \lambda(\mathbf{x}) \left(\frac{|p_x|^2}{|L_x|^\alpha + \varepsilon} + \frac{|p_y|^2}{|L_y|^\alpha + \varepsilon} \right) \quad (2)$$

The second term is the smoothing term, as shown in Eq. (2). Here, the subscripts x and y denote spatial differentiation of the template p and the log-luminance channel L . The objective of this term is to keep the gradients of p as small as possible, except across significant gradients in L .

There are three parameters in the smoothing term. The parameter ε is a small constant that avoids division by zero. The exponent α controls the sensitivity of the smoothness to the derivatives of L . To simplify our discussion, we take $\alpha = 1$ and $\varepsilon = 0.0001$ as the default settings, and they are used to produce all the results in this paper.

In our method, the most essential parameter is λ , which balances the weights of the data term and smoothing term. We could remove unwanted facial details by increasing λ . However, when λ is large, much illumination information of the template would also be discarded, which would weaken the relighting effect. It seems that a homogenous parameter λ of the WLS filter fails to achieve the suitable smoothing effect of the illumination template. To overcome this problem, we extend the original model to that with inhomogeneous λ and obtain spatially variant smoothing. In our modified model, λ is weighted according to different degrees of

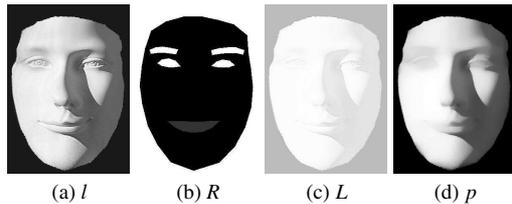


Fig. 3 (a) l is the luminance channel of the reference; (b) R is the weight of different facial regions that controls the parameter λ ; (c) L is the log-luminance channel; (d) p is the relighting template produced using the inhomogeneous edge-preserving smoothing filter.

smoothness in the corresponding facial regions, as shown below:

$$\lambda(\mathbf{x}) = c + 10 * R(\mathbf{x}) \quad (3)$$

where,

$$R(\mathbf{x}) = \begin{cases} 0, & \mathbf{x} \in \text{skin} \\ 0.2, & \mathbf{x} \in \text{mouth} \\ 1, & \text{otherwise} \end{cases} \quad (4)$$

In Eq. (3), the parameter λ is determined by two terms. The first term is a constant c (here $c = 1$), which controls the global smoothness of the template; the second term is a spatially varying function, which controls the local smoothness according to the weight for different facial regions, as shown in Eq. (4). Since most of the luminance information is in the skin and mouth, the weights in these regions should be small. In contrast, larger values are set in other regions to remove the unwanted identity and texture details.

Figure 3 illustrates the luminance of the reference l (the input of the WLS filter), the weight of facial regions R , the log-luminance L and the generated illumination template p (the output of the WLS filter). Comparing the input l and the template p , we see that the major luminance information of l is preserved well in p , while the unwanted details are effectively smoothed.

2.3 Face Relighting via Template

Using the generated illumination template p , face relighting is performed in CIELAB color space. Here, the original luminance channel of the target is denoted L_{in} , and the relighting luminance channel is denoted L_{out} . Then, $L_{out}(\mathbf{x}) = L_{in}(\mathbf{x}) * p(\mathbf{x})$. Composing L_{out} and the two color channels, we obtain the final relighting image.

3. Experiment

3.1 Face Relighting under Different Settings

To verify the performance of our relighting method, experiments were performed under different settings using various face databases.

One Target, Multiple Templates. It is fascinating to provide multiple templates for the user to select a suitable



Fig. 4 One Target, Multiple Templates. All the reference and target faces were taken from the YaleB Extended database [12].



Fig. 5 One Template, Multiple Targets. The target faces in the top row were taken from Lifespan face database [11], while the bottom row were taken from Caltech face database [13].

lighting style. In this situation, multiple illumination templates should be generated for the same target. We experimented on the YaleB Extended database [12], as shown in Fig. 4. It is seen that we can effectively transfer various shadow effects to the same target from faces with different identities.

One Template, Multiple Targets. In practical applications, some lighting styles are more commonly used than others. It would be convenient to form a template database covering typical lighting styles. Therefore, we relighted different targets with the same templates, as shown in Fig. 5. All the targets were taken from the Lifespan database [11] (top row) or Caltech face database [13] (bottom row). The results indicate our method can reliably relight different portraits using the same lighting style.

3.2 Comparison with Other Methods

We compare the results produced by our method and those of Li et al. [9] taken from [7], as shown in Fig. 6. In Fig. 6(c), the unwanted color information of the reference is transferred to the target with the relighting effect, which introduces apparent artifacts. This is due to the assumption in [9] that the reference and target should have similar skin color. In contrast, our method better preserves color and identity information of the target.

In Fig. 7, we compare our method (Fig. 7(e)) with that of [16] (Fig. 7(c)) and [7] (Fig. 7(d)) simultaneously. The

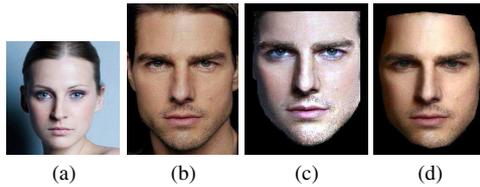


Fig. 6 Comparison with Li et al. [9]. (a) Reference. (b) Target. (c) Result produced by [9]. (d) Our result.



Fig. 7 Comparison with J. Chen et al. [16] and X. Chen et al. [7]. (a) Reference. (b) Target. (c) Result produced by [16]. (d) Result produced by [7]. (e) Our result.

results show that our method achieves lighting effect with better lighting detail and consistency. For example, [16] and [7] fail to transfer some highlight effects on the nose, and the lip is darkened. In our result (Fig. 7 (e)), not only are subtle local highlights and shadows of the reference reliably transferred, but also the target identity is well preserved.

4. Conclusion

In this paper, we propose a face relighting method using an illumination template. To effectively generate the template from the reference, we employ an edge-preserving filter with spatially variant smoothing based on the image-guided energy minimization framework. Experiments show the effectiveness of our method when applied to different databases under different settings.

However, the method has limitations according to our observation. Since ASM is used to locate landmarks, both the target and reference faces should be frontal. However, when the assumption is not satisfied, the relighting effect may introduce artifacts. For example, in the top row of Fig. 5, there is a long shadow on a face with a flat nose. Since this problem is mostly due to inaccurate face alignment, we could take more facial landmarks in a significant region or employ multi-pose face alignment [19] to improve the performance.

Currently, we restrict our method to a target with uniform lighting. When there is a hard shadow on the target, some illuminance normalization should be implemented [20]. However, to the best of our knowledge, there is no reliable related work addressing normalization for face relighting, which leaves room for future work.

When the skin region of the reference contains apparent details, such as a beard, hair or makeup, these details would be transferred to the illumination template as shadow, and may produce artifacts. This is an interesting problem that merits future study.

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