Robust Appearance Manipulation against Changes in the Lighting Environment

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ABSTRACT

Appearance control using model predictive controller with projector-camera system enables illusory by changing perceptual image by illumination projection. However, it leads to estimation errors and collapses the manipulation when the lighting environment changes. This paper proposes a robust reflectance compensation method that allows changes in the lighting environment.

1 Introduction

Projection mappings have been attracting a great deal of attention in the media, including television. The key technology for this projection mapping has been established by Raskar et al. in their work on Shader Lamps[1] as Spatial Augmented Reality. Since then, various geometric calibration and optical compensation methods have been proposed.

Amano et al. proposed Appearance Control[2], which uses a projector and a camera to manipulate the appearance with illumination projection through the feedback process. Furthermore, as its application, Amano et al. proposed the Shading Illusion[3]. It projects shading animation on the printed material by the appearance control according to the normal map embedded in color printing. Amano also proposed the coded facial expression (CFE), which applies this technique to the facial expression for printed pictures[4].

In the appearance manipulation, changes in ambient illumination caused by incident solar irradiation or room lighting condition will cause errors in the reflectance estimation and lead the saturation in the manipulated appearance. This problem can be solved by performing a photometric calibration for each lighting environment. However, performing calibrations during operation would seriously harm a sense of immersion.

In this study, we propose an appearance manipulation that is robust against changes in the lighting environment. Our method estimates illumination fluctuations through constraints on the color of the target object. In particular, this study focuses on facial expression manipulation using CFE, which manipulates facial expression on the printed picture, as shown in Fig. 1. Since the CFE requires a highly accurate reflectance estimation for the optical illusion, it is a good application to demonstrate our proposed method.

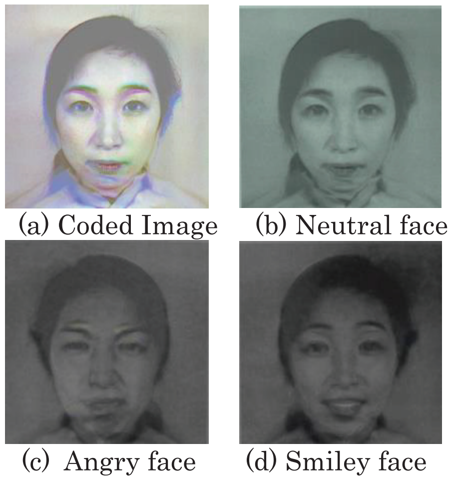


Fig. 1 Manipulated facial expression by CFE

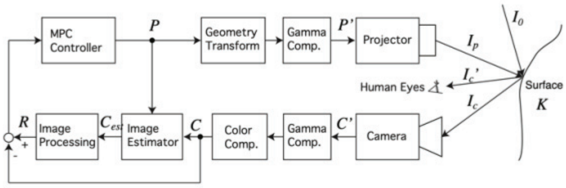


Fig. 2 Diagram of Appearance Control

2 Related Work

2.1 Appearance Control[2]

Appearance Control (AC) shown in Fig. 2 is achieved by feedback processing of the projector-camera using model predictive control. In AC, the camera first captures an apparent image $\boldsymbol{C}$ of the object to be operated. Next, the system estimates reflectance K of the object from the relation between RGB values of $\boldsymbol{C}$ and a projection image $\boldsymbol{P}$. Then, an appearance $\boldsymbol{C}_{est}$ under white illumination is obtained from the K in "Image Estimator". Next, a target image $\boldsymbol{R}$ is generated in "Image Processing" with a user-defined arbitrary image processing. Lastly, "MPC Controller" manipulates the appearance by adjusting $\boldsymbol{P}$ so that $\boldsymbol{R}$ and $\boldsymbol{C}$ are balanced by illumination projection.

CFE embeds three facial expressions in color printing[4]. These facial expressions are recovered from C_{est}, and the system displays one of the facial expressions by setting it as R.

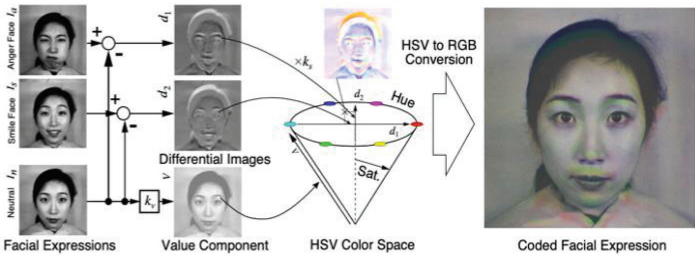


Fig.3 Facial Expression Coding

2.2 Coded Facial Expression[4]

CFE uses three facial expressions: neutral face, angry face, and smiling face and encodes these expression as shown in Fig. 3. The neutral face image $I_n(x,y)$ is assigned to the value component $V(x,y)$ in the HSV color space as

$$V(x,y) = k_v I_n(x,y) + 1 - k_v \tag{1}$$

where x, y are the image coordinates, and $0 < k_v \leq 1$ is the parameter that determines the contrast of the neutral face expression.

For the remaining images of angry face $I_a(x,y)$ and smiling $I_s(x,y)$, the difference from the neutral face $I_n(x,y)$ is calculated as follows.

$$d_1(x,y) = I_a(x,y) - I_n(x,y) \tag{2}$$

$$d_2(x,y) = I_s(x,y) - I_n(x,y) \tag{3}$$

These images decide location on the H-S plane by

$$H(x,y) = atan2\big(d_2(x,y), d_1(x,y)\big), \tag{4}$$

$$S(x,y) = k_s\sqrt{d_1^2(x,y) + d_2^2(x,y)}, \tag{5}$$

where $atan2(y,x)$ is the arc-tangent function with two arguments, 0< $k_s \leq 1$ is the color saturation parameter.

3 Proposed Method

3.1 Encoding conditions for printed material

The gray hypothesis[5], which posits that the colors in a scene are, on average, equally gray for R, G, and B, has been used to explain color constancy in human color perception. Based on this hypothesis, we proposed a method to simultaneously estimate physical and lighting color

In this study, inspired by the gray hypothesis, we create coded images with the constraint that the sum of the R, G, and B, components of the coded image is equal in CFE as follows.

$$\sum_{x=0}^{w}\sum_{y=0}^{h} k_{xy}^{r} = \sum_{x=0}^{w}\sum_{y=0}^{h} k_{xy}^{g} = \sum_{x=0}^{w}\sum_{y=0}^{h} k_{xy}^{b} \tag{6}$$

Where w, h are the width and height of the coded image, respectively, k^r, k^g and k^b are the R, G, and B, components of the coded image those are corresponding to the diagonal component of K.

3.2 Estimation of lighting environment components

In this study, we assume a situation where the lighting environment fluctuates during operation and describe its fluctuation by mixing additional illumination components with the environment that performed optical calibration. Especially, the color of the additional illumination is assumed to be constant and known, and its intensity is estimated by the following method.

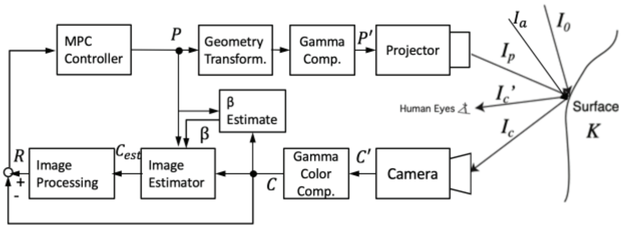


Fig. 4 AC with reflectance estimation compensation

Since the original AC does not assume fluctuation in environmental illumination $\boldsymbol{I_0}$, it leads to an error in estimated reflectance. To deal with this problem, we introduce an additional illumination $\boldsymbol{I_a}$ that expresses the difference from the standard illumination $\boldsymbol{I_0}$. With this component, we can rewrite reflected illumination on the surface as

$$\boldsymbol{I}_c = K\big(\boldsymbol{I}_p + \boldsymbol{I}_a + \boldsymbol{I}_0\big). \tag{7}$$

Where K is the reflectance ratio on the surface.

If the optical response of the camera and projector can be assumed to be linear, the reflectance of the target is estimated by

$$K = diag\{\boldsymbol{C}./(\boldsymbol{P} + \boldsymbol{C}_a + \boldsymbol{C}_0)\} \tag{8}$$

where ./ and ⊙ are element-wise division and multiplication, $\boldsymbol{C}_0$ and $\boldsymbol{C}_a$ are environment lighting components in the captured image. Here, the projection target is to accurately estimate the reflectance K. However, eq.(8) have many unknowns, and the R, G, and B component of $\boldsymbol{C_a}$ cannot be directly estimated alone only from eq.(6).

In this study, we assume the color of the additional illumination that changes the lighting environment is constant and known. We obtain its color in optical calibration that calculates differential image between capturing a white surface under the lighting environment with and without $\boldsymbol{I_a}$ in the condition that illuminated $\boldsymbol{I_0}$.

The captured arbitral intensity of additional light illuminated on the white surface can be written by

$$\boldsymbol{C}_a = \beta \boldsymbol{C'}_a\,. \tag{9}$$

where β and $\boldsymbol{C}_a$ are intensity and normalized color of additional illumination in captured image. From (6), (8), and (9), we obtain the following equation:

$$\boldsymbol{C_r}./(\boldsymbol{P_r} + \beta\boldsymbol{C}'_{ar} + \boldsymbol{C_{0r}}) = \boldsymbol{C_g}./(\boldsymbol{P_g} + \beta\boldsymbol{C}'_{ag} + \boldsymbol{C_{0g}})$$

$$= \boldsymbol{C_b}./(\boldsymbol{P_b} + \beta\boldsymbol{C}'_{ab} + \boldsymbol{C_{0b}}). \tag{10}$$

The error function to solve for the β is

$$E = \{\boldsymbol{C_r}./\left(\boldsymbol{P_r} + \beta\boldsymbol{C}'_{ar} + \boldsymbol{C_{0r}}\right) - \boldsymbol{C_g}./(\boldsymbol{P_g} + \beta\boldsymbol{C}'_{ag} + \boldsymbol{C_{0g}})\}^2$$

$$+\{\boldsymbol{C_g}./(\boldsymbol{P_g}+\beta \boldsymbol{C}'_{\boldsymbol{ag}}+\boldsymbol{C_{0g}})-\boldsymbol{C_b}./(\boldsymbol{P_b}+\beta \boldsymbol{C}'_{\boldsymbol{ab}}+\boldsymbol{C_{0b}})\}^2\ . \quad (11)$$

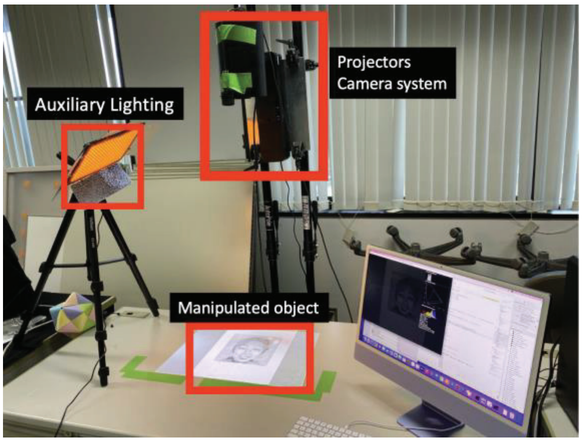


Fig. 5 Experimental setup

We obtained β to increase 0.01 from 0 to 3, and find the β that minimized E. This estimation procedure is implemented in "β Estimate" in Fig. 4. It gives additional illumination gain β and system estimates true reflectance

$$K = diag\{\boldsymbol{C}./(\boldsymbol{P}+\beta \boldsymbol{C}'_{\boldsymbol{a}}+\boldsymbol{C_0})\}. \quad (12)$$

With this K, it enables correct information display that is not affected lighting conditions.

4 Experiments

4.1 Experimental environment

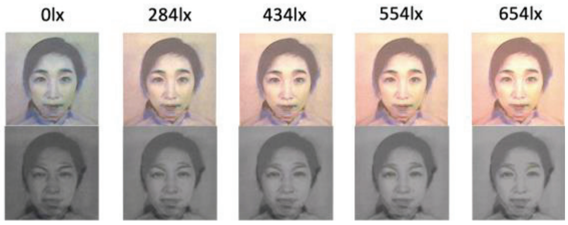
The experiment was conducted in an environment (86lx on the manipulated target) where the ceiling lights were turned on and blocked incoming light. As shown in Fig. 5, a camera and a projector are placed above the manipulation target, and additional orange lighting is used as a component to change the lighting environment. The color of additional lighting $\boldsymbol{C_a}$ is measured by the system camera and used as a previous knowledge. Three facial expressions, neutral, smiling, and angry, were chosen from the JAFFE[6] database and encoded into coded images with color adjustment to satisfy aforementioned constraints. Encoded images were printed on photo matte papers by a conventional inkjet printer.

4.2 Reflectance estimated and manipulation

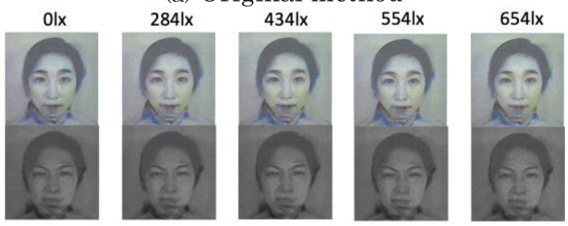
We used a printed coded image and investigated robustness against the change in illumination condition for the original method and our proposed method, as shown in Fig.6. Obviously, the original method (a) was directly affected by additional illumination in reflectance estimation and facial expression is not correctly manipulated. In contrast, our proposed method (b) achieved robust reflectance estimation and manipulated the target to correct facial expression for all illumination conditions.

4.3 Estimated reflectance in H-S color plane

Two facial expressions other than the neutral decide the location in the H-S plane in HSV color space after subtraction of the neutral image. Therefore, keeping the origin and correct direction in the H-S plane is key to



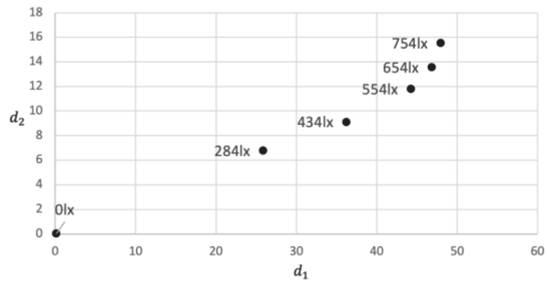
(a) Original method



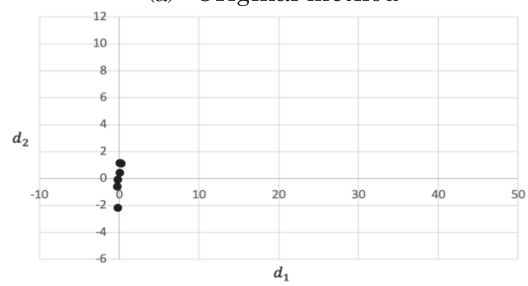
(b) Our proposed method

Fig. 6 Estimated reflectance(top) and manipulated appearance(bottom) under various lighting

correct decoding. Fig. 7 shows the average color of the



(a) Original method



(b) Proposed method

Fig. 7 Change in the average color of the estimated reflectance due to supplemental illumination.

estimated reflectance in each illumination condition for the original method and our proposed methods.

In this figure, d_1, d_2 are denoted horizontal and vertical in H-S planes. In the original method, the averaged color for the condition without additional illumination coincides with the origin in the H-S plane. However, it is away from the origin along with the increment of the additional illumination intensity. Contrary, our proposed method compensates estimated reflectance and its average color is plotted around the

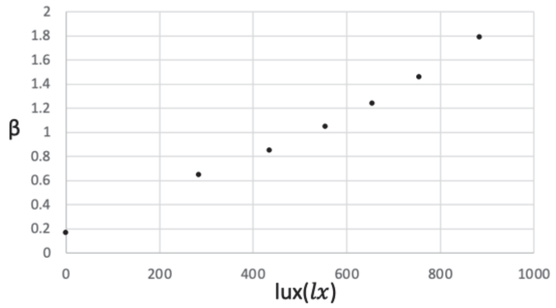


Fig. 8 Estimated illumination gain β.

origin in the H-S plane even when the illuminance of the additional illumination changes. From these results, it can be thought that the constraint in eq.(6) removes the reflectance estimation error and gives the correct intensity estimation of the additional illumination.

4.4 Estimated additional illumination gain

We evaluated the estimation results of the gain β for various additional illumination intensities, as shown in Fig.8. We can confirm that our proposed method successfully estimated the proportional relation to various additional illumination intensities. However, a small offset suggests residual estimation error, which should be removed in future work.

Since the colors of the additional lighting and the ceiling light are different, the color of the environmental light changes with the additional lighting gain β. Despite this, the β is successfully estimated. In another aspect, the difference in additional lighting and the ceiling light is a key to the estimation of β. Therefore, β estimation for the identical color additional lighting is impossible, but it does not harm the gray hypothesis of our encoding.

4.5 Manipulation results on various samples

We applied our proposed method to various Coded facial images. As shown in Fig. 9, we can see the robustness of our proposed method against illumination environment changes that not depending on the manipulation target.

5 Conclusions

In this paper, we introduced the condition in the average color of the coded image, which is inspired by the gray hypothesis, to solve the problem that the manipulation target cannot be accurately manipulated when the lighting environment changes for CFE. Based on the conditions, our proposed method estimates the correct reflectance not affected by environmental illumination fluctuation expressed by mixing known color additional illumination with static illumination environment.

Through the experiments, we confirmed our proposed method improved the robustness against illumination changes on CFE and estimated additional illumination gain. However, it has a small offset that suggests the remaining estimation error, and the error should be

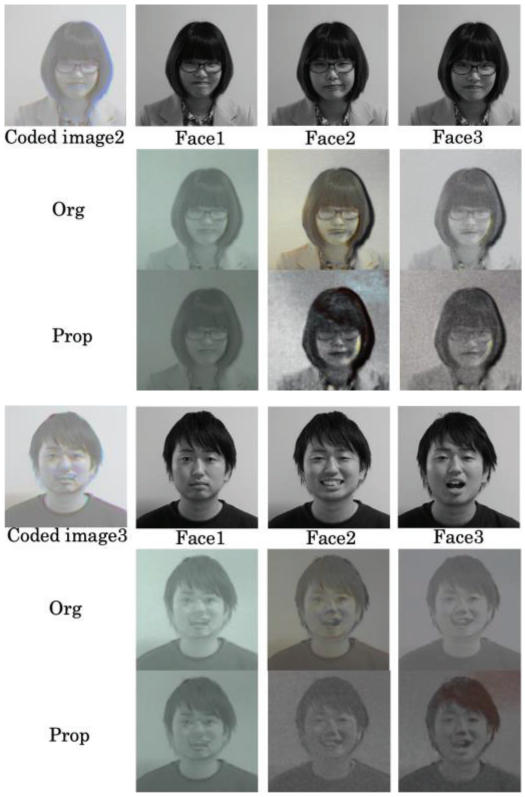


Fig. 9 Results on various facial samples

removed its error in our future work.

Our current method assumes the condition that the lighting environment changes uniformly in a whole captured image. However, the intensity of illumination has gradation in many lighting environments. Therefore, we will extend our method to pixel-wise processing to adapt to the situation that partially changes the lighting environment.

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