Perceptual Appearance Control by Projection-Induced Illusion

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ABSTRACT

When a projector displays images on real-world objects, result colors are affected by surface color and environmental light. Limited colors can be presented through projection because of these factors. We overcome this limitation by controlling projection color based on human perceived color.

1 INTRODUCTION

Object properties such as reflectance, texture, and material significantly affect an object's appearance. Projection mapping controls light reflected from the object to visually modify these properties. Nowadays, a lot of research employs a projector for controlling appearance of real objects [1, 2]. Given the degree of take-up of this technology, there is a pressing need for further improvement.

A projector controls appearance of real-world objects by adding illumination onto them, however they have an upper limit of presentable brightness. Because of this feature and spectral reflectance of the projected object, only limited colors can be presented by projectors. Projectors project light to a surface, and mixed light of both projected light and environmental light reflects on the surface. Environmental light become an offset of projection, and it decreases contrast of projection. Thus, presentable color range depends on reflectance of a projected surface and environmental light. Figure 1 shows how presentable color range becomes narrower by reflectance and environmental light. In Fig. 1-(a), ideal environment for projectors is shown. When there is no environmental light and the surface color is white, projected light completely reflects on the surface. When the projector projects blue, reflected light will be same blue color. In this situation, the performance of projectors is fully drawn out. By contrast, when the surface is not white (Fig. 1-(b)), the surface has prejudiced spectral reflectance. Depending on the spectral reflectance, light of some wavelength hardly reflect. In addition, when there is environmental light (Fig. 1-(c)), environmental light become offset and the contrast of the projection decreases.

In these situations, the performance of projectors cannot be fully drawn out and presentable color range

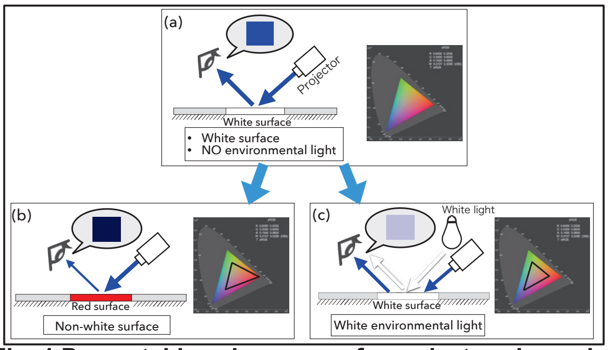

Fig. 1 Presentable color range of a projector depends on the surface color and environmental light. The range of (b) and (c) are narrower than that of (a).

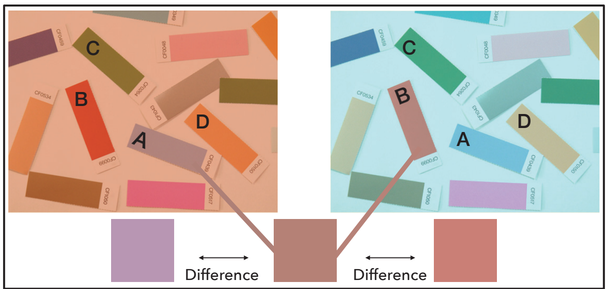

Fig. 2 Example of color constancy. Although the color of left A and right B look different, the two colors are physically the same.

becomes narrower. When the surface is red, the surface has spectral reflectance that only reflects red light strongly. Thus, even when the projector projects strong blue light, bright blue color cannot be presented unless the projector is much brighter than environmental light. In addition, when there is white environmental light in that environment, reflected light will be a mixture of white environmental light and blue projected light. Thus, only a pale color can be presented. In practical situations, there is almost no completely dark environments anywhere. Additionally, a projected surface often has chromatic color in projection-based application. Therefore, presentable color range of projectors almost always gets narrower because of these factors.

In order to broaden the range, we focused on human perception. Physical quantity of presentable colors are not always the same with perceived colors by humans.

Humans perceive color as a relative value which is affected by surrounding elements. For example, in Fig. 2, humans perceive the colors of A to D as relatively constant colors no matter whether environmental light is orange or cyan. However, actual colors are altered by the environmental light, and there are large differences between actual colors and colors perceived by humans. For example, the color of A on the left image and B on the right image look similar to the colors of the squares under the each image, respectively. Although these two colors look different perceptually, they are completely same color physically. This is an effect of color constancy, one of the visual illusions. A main purpose of a lot of projection based research is showing projection contents to humans. In other words, even if presented colors are physically not correct, there is no problem if the colors are perceptually correct.

Our idea is creating differences between physical and perceptual colors intentionally by inducing color constancy to broaden the presentable color range of projectors perceptually. In this paper, we explain our method that is improved from our first trials [3].

2 METHOD

This section describes how to control colors of objects perceptually by inducing color constancy. This section consists of two parts, one for inducing color constancy, the other for calculating suitable projection color.

2.1 Model for Inducing Color Constancy

Perceived colors of objects remain relatively constant under varying uniformed illumination conditions due to effects of color constancy [4]. Human vision system estimates colors of illumination and negates the effect of the colored illumination to perceive the original color of objects. In other words, if we can create a misunderstanding about the illumination color to observers, we can induce color constancy and control perceived color of objects. In the following, we explain how to create this misunderstanding of illumination color for controlling object color by using a projector.

Figure 3 shows the concept of our technique. We illustrate the case of changing object color from red to skyblue by light projection. We assume that the object's surface is a Lambertian surface, and we only focus on diffuse reflection. We separate the object into two areas, central area and surrounding area. The central area is red region and the surrounding area is gray area in the left figure in Fig. 3. The central area has reflectance $\mathbf{K}_c = diag(k_{c,r}, k_{c,g}, k_{c,b})$, and a combination of environmental light $\boldsymbol{l} = (l_r, l_g, l_b)^T$ and projection to central area $\boldsymbol{p}_c = (p_{c,r}, p_{c,g}, p_{c,b})^T$ is reflected on the surface. Reflected light from the central area $\boldsymbol{r}_c$ is expressed as

$$\boldsymbol{r}_s = \mathbf{K}_c(\boldsymbol{p}_c + \boldsymbol{l}). \quad (1)$$

Our eyes capture this reflected light to sense color of the central area. We call the physical color that is

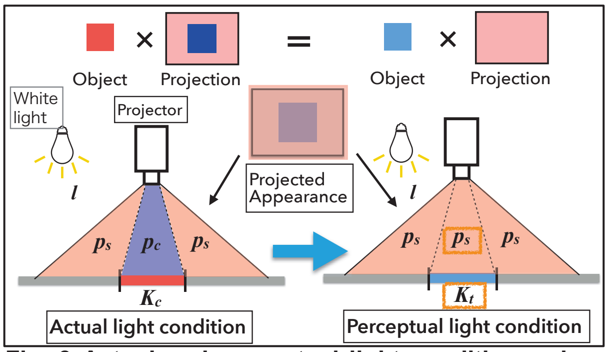

Fig. 3 Actual and perceptual light conditions when our system induce color constancy

determined by wavelength of light as actual color. We assume that the physically controllable range of projection $\boldsymbol{p}_c$ in each RGB channel is 0 to p_{max}. A physically controllable range of the reflected light $\boldsymbol{r}_c$ is determined by this range of $\boldsymbol{p}_c$. When the target color is inside this range, the projector can present the target color by $\boldsymbol{r}_c$ physically as an actual color. When the target is outside of the range, it is impossible to present it physically in the condition. In this case, we try to shift from the actual color to the target color perceptually by projecting $\boldsymbol{p}_s$ to the surrounding area to induce color constancy. We introduce the target color that has reflectance $\mathbf{K}_t = diag(k_{t,r}, k_{t,g}, k_{t,b})$. In Fig. 3, this target color is skyblue. When this skyblue object is under uniformed colored illumination, like right side in Fig. 3, humans perceive the object color as skyblue relatively because of the color constancy effect. When the projection $\boldsymbol{p}_s$ and the environmental $\boldsymbol{l}$ are projected to the area that has reflectance $\mathbf{K}_t$, the reflected light $\boldsymbol{r}_t$ can be obtained by an equation below.

$$\boldsymbol{r}_t = \mathbf{K}_t(\boldsymbol{p}_s + \boldsymbol{l}) \quad (2)$$

When these reflected light $\boldsymbol{r}_c$ and $\boldsymbol{r}_t$ are completely same, we can reproduce light condition on the right side of Fig. 3 by projecting $\boldsymbol{p}_c$ and $\boldsymbol{p}_s$ like the figure on the left of Fig. 3. By reproducing this perceptual light condition, observers perceive that the object with the target color $\mathbf{K}_t$ is under uniformed colored light $\boldsymbol{p}_s$. To obtain the projection $\boldsymbol{p}_c$ and $\boldsymbol{p}_s$ which can present the target color, we need to minimize the following cost function.

$$\boldsymbol{p}_c, \boldsymbol{p}_s = \underset{\boldsymbol{p}_c, \boldsymbol{p}_s}{\arg\min} |\mathbf{K}_c(\boldsymbol{p}_c + \boldsymbol{l}) - \mathbf{K}_t(\boldsymbol{p}_s + \boldsymbol{l})| \quad (3)$$

When the result of eq. (3) is zero, humans understand that single colored uniformed illumination $\boldsymbol{p}_s$ is projected, and original color of the object is $\mathbf{K}_t$. However, with only this cost function, we cannot obtain suitable projection colors $\boldsymbol{p}_c$ and $\boldsymbol{p}_s$. We explain how to determine suitable projection colors in next section.

2.2 Method for Calculating Suitable Projection Color

Our method requires projecting colored illumination to surrounding areas even when we do not want to change the colors of the areas. Thus, we define a suitable projection color of $\boldsymbol{p}_s$ as a color that is the closest to achromatic.

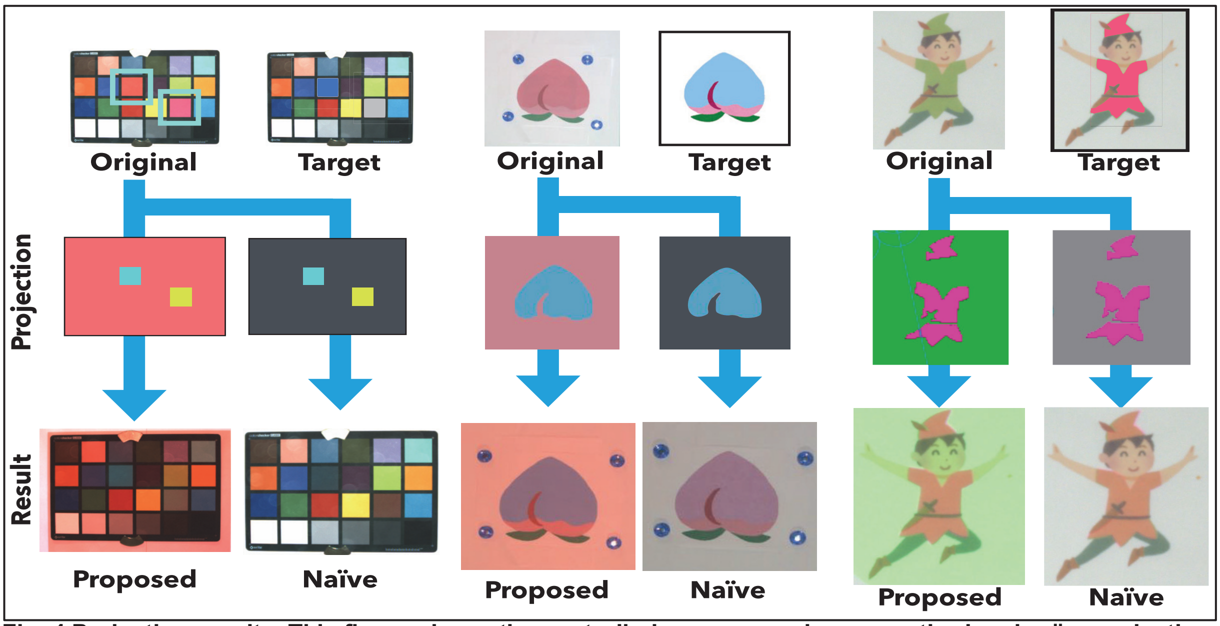

Fig. 4 Projection results. This figure shows the controlled appearance by our method and naïve projection.

In this algorithm, we focus on reproducing target reflectance. In other words, we do not care about brightness of the target color, and we focus on hue and color saturation in HSV color space. When projectors can physically present the target color without our method, there is a $\boldsymbol{p_c}$ that satisfies

$$\mathbf{K_c}(\boldsymbol{p_c} + \boldsymbol{l}) = gain\, \mathbf{K_t}\boldsymbol{u}. \quad (4)$$

where $\boldsymbol{u} = (1, 1, 1)^T$ and $gain$ is a scalar value. The left-hand side of eq. (4) is RGB values of reflected light from a projected surface, and the right-hand side is diagonal elements of the target reflectance. When there is no $\boldsymbol{p_c}$ that satisfies eq. (4), our algorithm finds $\boldsymbol{p_c}$ that can present as close as the target color within the projector's presentable range $0 \leq \mathrm{p_{c,i}} \leq \mathrm{p_{max}}$ $(i \in \{r, g, b\})$. After $\boldsymbol{p_c}$ is determined, $\boldsymbol{p_s}$ can be calculated as

$$\boldsymbol{p_s} = \frac{\mathbf{K_c}}{\mathbf{K_t}}(\boldsymbol{p_c} + \boldsymbol{l}) - \boldsymbol{l} \quad (5)$$

The resulting $\boldsymbol{p_s}$ and $\boldsymbol{p_c}$ make the residual of the cost function eq. (3) zero. Thus, we can induce color constancy and present the target color by projecting $\boldsymbol{p_c}$ to the center area and $\boldsymbol{p_s}$ to the surrounding area. When all values of $\boldsymbol{p_c}$ are positive, calculated values become $p_{s,r} = p_{s,g} = p_{s,b}$, which means $\boldsymbol{p_s}$ is an achromatic color. In addition, when original color and target color are too far apart, $\boldsymbol{p_s}$ can have negative value. In that case our system cannot represent the target color perceptually.

3 RESULTS

Based on our method, we developed an application that can automatically control perceptual colors by inducing color constancy. The system consists of a projector, a camera, and a computer. Figure 4 shows three application examples of our system. In the third row shows the result images by our method and naïve projection. Although physical colors of each pairs are completely the same, perceptual colors are different.

4 CONCLUSION

We presented a projection technique that can broaden presentable color range of projectors perceptually by inducing color constancy, and showed several application examples of our method. In research field of augmented reality, perceptually-based approaches are proposed recently [5]. These approaches employ effects of human vision system in order to archive research goals that are physically difficult or impossible. We believe we need to take perception into consideration to augmented reality.

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