Perceptual Appearance Control by Projection-Induced Illusion

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Abstract

Using projection mapping, we can control the appearance of real-world objects by projecting colored light onto them. Since a projector can only add illumination to the scene, limited color gamut can be presented through projection mapping. However, actual color and perceived color are not always the same, and there is often large difference between them. We intentionally generate this difference by inducing visual illusion for extending the controllable color gamut of a projector. In particular, we induce color constancy. We demonstrate changing object color with and without inducing color constancy. Audiences perceive the controlled colors with and without illusion as different color nevertheless these colors are physically completely same.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Mixed / augmented reality; Computing methodologies—Computer graphics—Graphics systems and interfaces—Perception

1 Introduction

Object properties such as reflectance, base color, and texture significantly affect an object's appearance. Projection mapping is a technology that modifies these properties to control an object's appearance. Jones et al. [5] utilize multiple projectors and depth cameras to convert a room into a mixed reality environment that can be shared with other people.

Projection systems manipulate appearance by overlaying light projection onto an object's surface. The color perceived by an observer depends on the combination of the projected light and the surface color. Modulation of the projected color by the background is the largest drawback of projection systems, since the system cannot manipulate the appearance to match a color that cannot be represented as a mixture of these colors. For example, a red object cannot be made to appear blue, even if blue light is projected onto it by a powerful projector because it mainly reflects red light and absorbs the majority of blue and green light.

In this paper, we explore how to extend the color gamut a projector system can express by considering human perception of color. We perceive the color of an object as a relative value that is influenced by the color of its surroundings. This leads to the phenomenon of color constancy in certain situations where a large difference between the perceived and actual color of an object can be observed. Our idea is to employ color constancy to present colors perceptually that cannot be generated by naïve projection mapping approaches.

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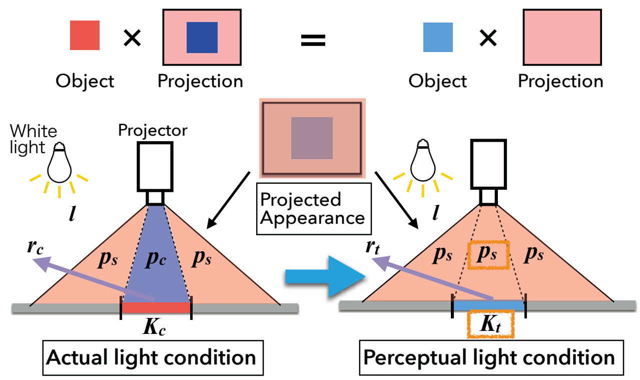

Figure 1: Concept of this work.

2 Related Work

In projection-based research, most studies employ projector-camera systems to control the appearance of the projection surface. Radiometric compensation technology can negate the effect of colors and texture on a projection surface in order to reproduce as closely as possible the intended appearance of digital content [4]. In contrast to the compensation, Amano et al. [3] developed a method to control an object's appearance by light projection based on its original appearance. This work utilizes the original appearance of an object to enhance some of its elements, like color saturation, color brightness, edges, and so on. Akiyama et al. [2] extended their method to estimate both the object's reflectance and environmental light simultaneously to control the object's appearance in dynamic lighting conditions. These methods assume that the colors captured by a camera are identical to those perceived by human which is not always the case.

Human perception has been exploited by Kawabe et al. [6] to create an illusion of motion with light projection on a static object. To create this illusion, they project a dynamically modified grayscale image to vary the luminance. This continuous modification is perceived as motion by observers. Although this work also induces a visual illusion, they focus on perceptual movement. On the other hand, we focus on the manipulation of an object's perceived color. Madi et al. [8] created a model of color constancy for projection color compensation. They consider visual color illusion to simulate the appearance of an object under different conditions, and they applied their system to preserve the perceived appearance of images. Contrary to their system, our goal is to freely control an object's color by taking human color perception into consideration.

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3 APPROACH

Perceived color of objects remains relatively constant under varying uniformed illumination conditions due to effects of color constancy [7]. Human vision system estimates color of illumination and negate the effect of the colored illumination to perceive original color of objects. In other words, if we can create misunderstanding about estimation of illumination color, we can freely induce color constancy and control perceived color of objects. In this section, we explain how to create misunderstanding of illumination color for controlling object color with using a projector.

Figure 1 shows the concept of our technique. We illustrate the case of changing object color from red to skyblue by light projection. We regard the object's surface is Lanbertian surface, and we only consider about defuse reflection. We divide the object to two areas, central area and surrounding area. The central area has reflectance $\mathbf{K_c} = \mathrm{diag}(k_{cr}, k_{cg}, k_{cb})$, and white environmental light $\boldsymbol{l} = (l, l, l)^{\mathrm{T}}$ and projection to central area $\boldsymbol{p_c} = (p_{cr}, p_{cg}, p_{cb})^{\mathrm{T}}$ are reflected on the surface. Reflected light from the central area $\boldsymbol{r_c}$ is expressed by the equation below.

$$\boldsymbol{r_c} = \mathbf{K_c}(\boldsymbol{p_c} + \boldsymbol{l}) \tag{1}$$

Our eyes capture this reflected light to sense color of the central area. We call this color as actual color, and we try to shift from this color to target color by using projection to surrounding color $\boldsymbol{p_s}$. For deciding $\boldsymbol{p_s}$, we introduce the target color which has reflectance $\mathbf{K_t}$. In Fig. 1, this target color is skyblue. When an object which has this color is under uniformed illumination, we perceive the color relatively constant even if the illumination is colored. Thus, we estimate reflected light of environmental light $\boldsymbol{l}$ and projection to surrounding area $\boldsymbol{p_s}$ which is reflected on the target reflectance $\mathbf{K_t}$. This reflected light $\boldsymbol{r_t}$ can be estimated by equation below.

$$\boldsymbol{r_t} = \mathbf{K_t}(\boldsymbol{p_s} + \boldsymbol{l}) \tag{2}$$

When these reflected light $\boldsymbol{r_c}$ and $\boldsymbol{r_t}$ are completely same, we can reproduce light condition on the right of Fig. 1 by projecting $\boldsymbol{p_c}$ and $\boldsymbol{p_s}$ like the figure on the left of Fig. 1. By reproducing this perceptual light condition, observers perceive that the object with target color is under uniformed colored light. To obtain the projection $\boldsymbol{p_c}$ and $\boldsymbol{p_s}$ which can present target color, we need to solve cost function below.

$$\boldsymbol{p_c}, \boldsymbol{p_s} = \underset{\boldsymbol{p_c}, \boldsymbol{p_s}}{\arg\min} \left|\mathbf{K_c}(\boldsymbol{p_c} + \boldsymbol{l}) - \mathbf{K_t}(\boldsymbol{p_s} + \boldsymbol{l})\right| \tag{3}$$

4 DEMONSTRATION SYSTEM

Our system consist of a projector, a camera, and a computer. The camera captures the target object, and the computer calculates suited projection color for presenting target reflectance. After the calculation, the projector projects the calculated color to the object. The system estimates the object's reflectance in real time based on the method defined by Amano et al. [3]. We show controlled appearance of the object with and without utilizing our method (projecting white light to surrounding area). Observers perceive these colors different despite the actual colors are exactly the same.

In this demonstration, we use printouts as target objects. Our system is going to change the object's color to the color which cannot be presented by naïve overlaying projection. For example, controlled appearance is shown in Fig. 2. In this figure, the original color of the object is green, and we would like to change the color to orange. However, orange is far color from green and it is difficult to change. The projected result by naïve overlaying projection is Fig. 2 (b). However, by inducing color constancy by our method, we perceive color in Fig. 2 (c) as orange color, nevertheless actual color is not changed from (b). Observers can experience this visual illusion and understand how human visual system can easily be influenced by external factors. A short movie of our demo is available at [1].

(a) (b) (c)

Figure 2: Controlled appearance. Actual color of clothes in (b) and (c) are completely same. (a) original appearance under white illumination, (b) controlled appearance by projecting colored illumination to only clothes and the hat, (c) controlled appearance by our method.

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