# Light Projection-Induced Illusion for Controlling Object Color


Ryo Akiyama[*] Nara Institute of Science and Technology

Goshiro Yamamoto[†] Kyoto University

Toshiyuki Amano[‡] Wakayama University

Takafumi Taketomi[§] Nara Institute of Science and Technology

Alexander Plopski[¶] Nara Institute of Science and Technology

Christian Sandor[‖] Nara Institute of Science and Technology

Hirokazu Kato[**] Nara Institute of Science and Technology



## Abstract

Using projection mapping, we can control the appearance of real-world objects by projecting colored light onto them. Because a projector can only add illumination to the scene, only a limited color gamut can be presented through projection mapping. In this paper we describe how the controllable color gamut can be extended by accounting for human perception and visual illusions. In particular, we induce color constancy to control what color space observers will perceive. In this paper, we explain the concept of our approach, and show first results of our system.



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


## 1 Introduction

An object's appearance is affected by a variety of factors, like reflectance, color, and texture. By modifying these factors through projection mapping it is possible to alter the 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. Their system projects light not only onto the walls of the room, but also the players to create an immersive experience. Similarly, Fujimoto et al. [4] manipulate the appearance of a deformable cloth by projecting the desired pattern onto it to assist designers in evaluating their work.

Projection systems manipulate appearance by overlaying colored light onto the surface. The projected light mixes with the surface's color and is perceived by an observer. The mixing of the background and projected color is the largest drawback of projection systems, because 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 how humans perceive colors. We perceive the color of an object as a relative value that is influenced by the color of its surroundings. Therefore, in some cases there is a large difference between the perceived and actual color of an object. This phenomenon is called color constancy. Our idea is to employ color constancy to present colors that cannot be generated by naïve projection mapping.


[*]e-mail: akiyama.ryo.ah7@is.naist.jp
[†]e-mail: goshiro@kuhp.kyoto-u.ac.jp
[‡]e-mail: amano@sys.wakayama-u.ac.jp
[§]e-mail: takafumi-t@is.naist.jp
[¶]e-mail: plopski@is.naist.jp
[‖]e-mail: sandor@is.naist.jp
[**]e-mail: kato@is.naist.jp



IEEE Virtual Reality 2018
18-22 March 2018, Reutlingen, Germany



## 2 Related Work

In projection-based research, most studies employ a projector-camera system to control projection colors and to optimize the appearance of the projection surface. Radiometric compensation technology can negate the effect of colors or texture on a projection surface in order to reproduce as closely as possible the intended appearance of digital content [3]. In contrast to the compensation, Amano et al. [2] 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. Akiyama et al. [1] 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. However, this is not necessarily the case.

Human perception has been exploited by Kawabe et al. [6] to create an illusion of motion 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 the perceived object color. Madi et al. [7] 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. 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 accounting for how the scene is perceived by a human observer.

## 3 Projection Method

In this section, we explain the color gamut of a projection mapping system and how it can be expanded by inducing color constancy.

### 3.1 Limitation of Simple Overlaying Light Projection

As we mentioned before, the color gamut that can be expressed by projection mapping is limited, because the projector is adding light to the scene. The limitation depends on the object's reflectance, the environmental light, and the specifications of the projector. In this section, we explain how we can present colors that are outside the presentable range. We assume that the scene consists only of lambertian surfaces and is illuminated by white light.

Let $C_L$ be the color of the real-world object under white environmental light, and $C_P$ the color of the projected light that has been reflected off the object's surface. This light can be controlled by adjusting the color emitted by the projector. Our eyes capture the summed reflected light $C = C_L + C_P$. As shown in Figure 1, by modifying the projected light, we can control $C_P$. $C$ can appear as

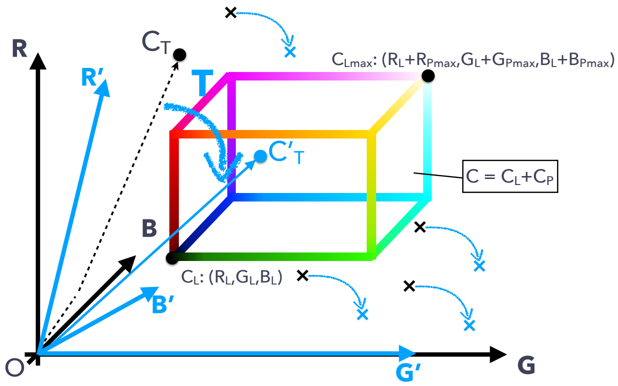


Figure 1: Through projection mapping a $C_L$ colored object can appear as any color within the color gamut represented by the colorful cuboid. It thus cannot appear as $C_T$ which lies outside. The axes R, G, and B represent the brightness of the reflected elements of red, green, and blue, respectively. Color constancy transforms the color space by T. $C_T$ is transformed to $C'_T$ which falls within the color gamut.

any color within the color gamut (represented by the colorful cuboid) In other words, colors outside of the cuboid cannot be presented in this condition. If we use a more powerful projector, the cuboid becomes larger. In addition, if environmental light is darker, the cuboid approaches the origin point. Therefore, the color gamut is mainly determined by the specifications of the projector and environmental light.

### 3.2 Method

In this section, we explain a scheme for presenting a color that is outside of the controllable range by inducing color constancy. Assume that for a user to perceive the color $O_T$, $C_T$ must be reflected off the surface of the object. If the vector towards $C_T$ intersects the cuboid, it can be presented by naïve projection. However, if the vector does not intersect the cuboid, as shown in Figure 1, it cannot be presented. Our method can be applied to manipulate the object's appearance, so that an observer nonetheless perceives the reflected color as $O_T$.

By color constancy effect, humans perceive colors as relatively constant even under different uniform environmental light. This can be explained as converting color spaces. In Figure 1, due to color constancy the RGB space is converted to R'G'B' space by the conversion matrix T.

In order to calculate T we need to consider the colors $C_T$ and $C_S$, the color of its surrounding area. $C_S$ is determined by the object's reflectance $K_S = diag(k_{s1}, k_{s2}, k_{s3})$ and the environmental light $L = (R_L, G_L, B_L)^\mathrm{T}$ as $C_S = K_S L$. By projecting $P_s = (R_s, G_s, B_s)^\mathrm{T}$ onto the surrounding area, $C_S$ appears as $C'_S$. Given the additive feature of projection mapping systems, $C'_S$ can be described as

$$C'_s = K_s(P_s + L) = \lambda \mathrm{T} K_s L, \tag{1}$$

where $\lambda = \|C'_s\|/\|C_s\|$. T can thus be recovered from $C'_S$, $C_S$, $K_S$ and $L$. Although $P_S$ is not projected onto $C_T$ it appears as

$$C'_T = \mathrm{T} C_T \tag{2}$$

due to color constancy. Our goal is thus to find a suitable $P_S$ so that the resulting color $C'_T$ falls within the color gamut of our system.

We show an example of our projection system being used in Figure 2. Our goal is to modify the appearance of two colors (highlighted by blue rectangles) on a ColorChecker target. In particular, we want to change rose and pink colors to blue and gray, respectively. By simply projecting a correction color onto the target area, the appearance does not match the target colors. However, by projecting a reddish environmental light over the other areas of the scene, observers perceive the intended colors.

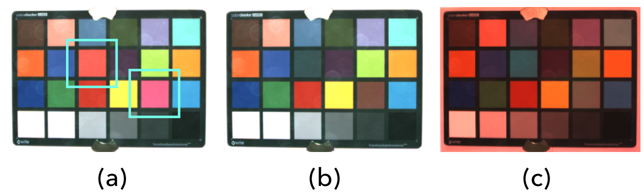

Figure 2: Experiment results: (a) We want to change the appearance of the rose and pink colors to blue and gray, respectively. (b) The target appearance cannot be achieved by simple projection mapping. (c) By inducing color constancy we achieve the target appearance.

## 4 Conclusion and Future Work

Projection mapping systems have a limited controllable color gamut due to their additive feature. The goal of this work is to expand this color gamut.

In this paper we describe the color gamut that can be controlled by projectors and how colors that fall outside the color gamut of a projection system can be presented by inducing color constancy. Our computations assume that the color modification is a linear function. In RGB space this only holds for the projector. A linear modification of the color in RGB space does not necessarily translate to a linear modification of the perceived color. In the future we aim to modify our model to account for this. For example, the perceptual color could be represented in the Lab color space, which is perceptually linear. Finally, we will conduct a user study to verify if our method can expand the perceived color gamut of a mapping system.

We believe that our system can also assist people who suffer from color-vision deficiency. In the future, we want to investigate if by manipulating the appearance with our system, color-deficient observers can perceive colors they are not able to see naturally.

## Acknowledgments

This work was supported by ACT-I, JST.

## References


[1] R. Akiyama, G. Yamamoto, T. Amano, T. Taketomi, C. Sandor, and H. Kato. Appearance Control in Dynamic Light Environments with a Projector-Camera System. In *Proceedings of the IEEE VR Workshop on Perceptual and Cognitive Issues in AR*, pages 1–6, 2016.

[2] T. Amano and H. Kato. Appearance Control Using Projection with Model Predictive Control. In *Proceedings of the International Conference on Pattern Recognition*, pages 2832–2835, 2010.

[3] O. Bimber, A. Emmerling, and T. Klemmer. Embedded Entertainment with Smart Projectors. *Computer*, 38(1):48–55, 2005.

[4] Y. Fujimoto, R. T. Smith, T. Taketomi, G. Yamamoto, J. Miyazaki, H. Kato, and B. H. Thomas. Geometrically-Correct Projection-Based Texture Mapping onto a Deformable Object. *IEEE Transactions on Visualization and Computer Graphics*, 20(4):540–549, 2014.

[5] B. Jones, R. Sodhi, M. Murdock, R. Mehra, H. Benko, A. Wilson, E. Ofek, B. MacIntyre, N. Raghuvanshi, and L. Shapira. RoomAlive: Magical Experiences Enabled by Scalable, Adaptive Projector-Camera Units. In *Proceedings of the ACM Symposium on User Interface Software and Technology*, pages 637–644, 2014.

[6] T. Kawabe, T. Fukiage, M. Sawayama, and S. Nishida. Deformation Lamps: A Projection Technique to Make Static Objects Perceptually Dynamic. *ACM Transactions on Applied Perception*, 13(2):10:1–10:17, 2016.

[7] A. Madi and D. Ziou. Color Constancy for Visual Compensation of Projector Displayed Image. *Displays*, 35(1):6–17, 2014.