# Layered Shadow: Multiplexing Invisible Shadow Using Infrared Lights with Different Wavelengths

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## ABSTRACT

This paper proposes a multiplexing invisible shadow system named "Layered Shadow." The proposed system uses infrared lights, each of which radiates a certain wavelength of infrared light, and an object to which two different types of IR filters are attached. Directing the light toward the object causes the object's shadow to appear; the shape of the object then appears to change according to the wavelength of the radiated infrared light. With this system, a user is expected to attain a different viewpoint on shadows.

## Categories and Subject Descriptors

H.5 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Artificial, augmented, and virtual realities*

## General Terms

Design

## Keywords

Shadow, Multiplexing Infrared Light, De-familiarization, Entertainment system

## 1. INTRODUCTION

We recognize shadows unconsciously in every day. Many people recognize common features of shadows (e.g., the color is only black or achromatic, the shape is the same as that of the object that casts the shadow, and the shadow follows the object's movement or the light source's location). Shadows are a phenomenon always generated by light. However, we rarely think about their existence, so we recognize such stereotypes. Otherwise, shadows have close connections with the entertainment field. They are a familiar element in traditional performances such as shadow puppetry. In such performances, the properties of shadows, such as mimicking an object's shape and movement, are exploited.



Shadows are a phenomenon generated by an object selectively blocking rays of light. Thus, they have the same shape as the outline of the object, but many visual characteristics (e.g., colors and lines) of the object are eliminated, so the color is only black or achromatic. Therefore, the shadow has less detail than the object and is simplified. We chose to reverse this relationship by generating a shadow with more details than the object. The purpose of this was to allow the user to become aware of a different viewpoint by intentionally subverting normal expectations, specifically, the idea that a shadow is always simpler than the object that casts it and has the same shape as the outline of the object.

## 2. RELATED WORKS

Several studies have tried to extend shadows to applications in media arts. KAGE, which was developed by Chikamori *et al.*, generates object shadows with computer graphics and projects them from the ceiling [1]. The user can play with the shadow, which changes shape and color, by touching conic objects with touch sensors. Textured Shadow/Movie-in-Shadow, developed by Minomo *et al.*, is a multi-projection system that changes the shadow of the user into a colorful one by using complementary colors [2]. This system projects two different images from two projectors to the same region of the floor. The projected images are complementary colors, so the illuminated part of the floor is white. When the user treads on the illuminated part of the floor, the lights from the projectors are turned off, and complementary colors are removed from the user's shadow. This makes the user's shadow colorful. Our proposed system is similar to that of Chikamori *et al.* in that it generates a shadow with a shape different from that of the object, but it is different with regard to its multiplexing of the shadow by using different light wavelengths. Our system is also similar to that of Minomo *et al.* in that it increases the details of the shadow, but it is different in that it captures the details of the object by using infrared light sources with multiple wavelengths.

## 3. SYSTEM COMPONENTS

Figure 1 shows an outline of the system. This system consists of infrared light sources, a camera, a PC, a projector, a horizontal screen that forms the top of a table, and objects to create shadows. When the user shines the infrared light toward the object, an invisible shadow is created on the screen. The camera captures the table surface. An IR-76 filter is attached to the lens of the camera to allow infrared light with a wavelength of over 760 nm to be transmitted, so

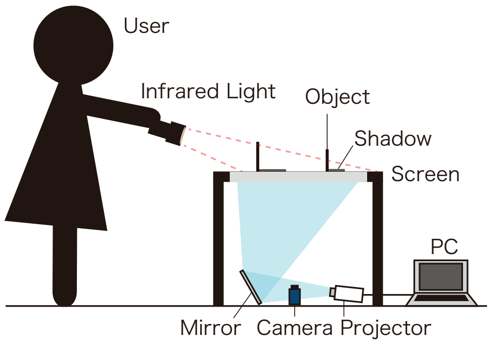



**Figure 1: System components**

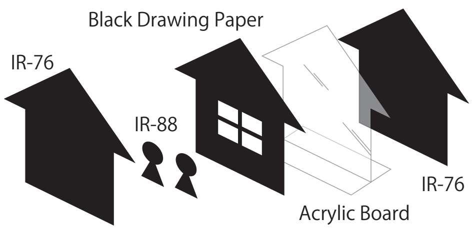



**Figure 2: Object structure**

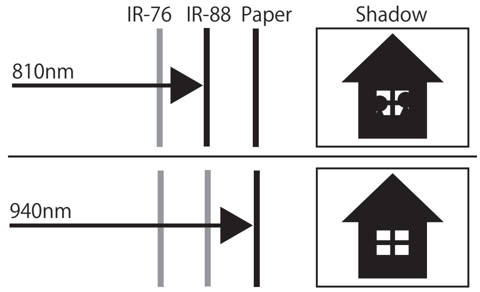
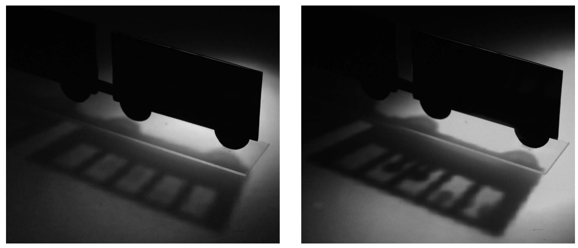



**Figure 3: Shadow shapes cast by different lights**



(a) *with 940nm IR light* (b) *with 810nm IR light*

**Figure 4: Shadows generated by IR lights**

that the camera can capture the shadow cast by the infrared light. The captured image is projected onto the screen by the projector. In this process, real-time image processing by the OpenCV software (http://opencv.org/) calibrates the positions of the shadows in the image projected by the projector and the positions of the objects. The screen is made of a material used for rear projection, so it enables projection of both invisible shadows by infrared light and images by the projector. This system uses two types of handheld lights with different wavelengths, 810 nm and 940 nm, as the infrared light sources. Figure 2 shows the structure of the object used to cast invisible shadows. IR filters are included as layers of the object. IR-76 filters are used on the outside of the object, and IR-88 filters are used inside of the object. These two types of filters and a material to block all of the light — in this case, a piece of black drawing paper — are attached, so the object has three layers. Figure 3 shows how the object design is expected to selectively transmit and block light at two different wavelengths.

## 4. APPLICATION

We created an application to present the object shadow that has more detail than the real object. The object appearance is only a black outline of a house shape, but the projected shadow has the shape of a house with more detail (i.e., the shape of shadow is a house with a window). By shining infrared light on the object standing on the screen, the object shadow, which has a different profile than the object, appears on the screen. Shadows that the user can see are "extended shadows" from the projector, so shadows that differ from the standard experience of shadows (that is, that they always take the shape of the outline of the objects that cast them) can be created. Figure 4 shows pictures of the system at work: Figure 4-(a) shows the shadow of a train generated by illuminating with 940 nm infrared light. The train object does not have windows, whereas its shadow has windows. Figure 4-(b) shows the shadow of a train generated by illuminating it with 810 nm infrared light. The passengers and straps appear in the generated shadow.

## 5. CONCLUDING REMARKS

This paper has proposed a system that can generate shadows of different shapes. The system uses infrared lights at multiple wavelengths. The system can provide an unconventional viewpoint by intentionally shifting the user's preconceptions, i.e., the idea that a shadow is simpler than the corresponding object. In future work, we will attempt to expand the latitude of expression by combining the capture of shapes of invisible object shadows with capturing markers [3]. We are in the process of developing a novel application using this technique.

## Acknowledgment

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