Master's Thesis in Graduate School of
Library, Information and Media Studies

High-Speed Projection Method to Prevent Secret Photography with Small Cameras

March 2021
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High-Speed Projection Method to Prevent Secret Photography with Small Cameras
高速プロジェクタを用いたコンテンツ保護技術

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Secret recordings using smartphones have become a serious problem for content providers. We present a new method to protect projected images and other information (*i.e.*, "recordable content") from secret photography by using high-speed projection. Our purpose in this study is to develop and implement a projection method that allows people to observe photographable objects, people, and events while preventing the same from being recorded by cameras and other recordable devices. To achieve this goal, we focus on the difference between human and camera vision systems. Unlike cameras, human beings cannot recognize the high-speed changes of light. We divide an image into two or more parts and project them in succession at a high frame rate such that a full image is made visible to human eyes. By contrast, cameras can only capture an incomplete frame.

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March 2021

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Chapter 1

Introduction

Protecting images and information (recordable content) projected on a screen is a difficult problem. Although protection techniques for digital copies have been discussed for many years, recordable content projected by general display techniques (*e.g.*, LCDs, projectors) is not only visible to the humans but can also be captured by cameras. In this cases, that which is “visible to human eyes” is nearly the same as being “recordable by a camera”. Thus, projected recordable content is sometimes secretly captured by small cameras even when protection techniques against digital copies have been adopted.

Some solutions exist to prevent such recordable copies by camera devices. The first solution is to overlay something that appears to the human eye (*e.g.*, visible watermarks, stickers of credit) on contents. Examples are shown in Figure 1.1. This is a very simple and effective solution, as a camera cannot capture the content as it is. However, in this case, people similarly cannot see the content as it is. Therefore, this method worsens the experience of viewers. The second solution involves inspection and security, which are illustrated in Figure 1.2. For example, an organizer of an event can confiscate camera devices before visitors enter an area in which that content can be captured. Even if the inspection overlooks some cameras, warnings might be issued not to use cameras. However, event visitors secretly taking pictures is still possible. Ill-intentioned visitors (*e.g.*, ranging from those who wish to infringe on the privacy of others to those who violate copyright protections) can use small cameras (*e.g.*, pen-shaped secret cameras, a smartphone hidden in a breast pocket, wearable eyeglass-like devices) to take photographs secretly. In this study, we develop and evaluate a new form of protection against these types of secret cameras.

To achieve our goals, we examine the difference between human and camera vision systems. Unlike cameras, humans cannot recognize the high-speed changes of light [1]. We were inspired by a previous study that considered these properties. Several studies have tried to present imperceptible on-screen markers using high-speed projection between the afterimage effect produced in human eyes and the shutter speeds of digital cameras [2, 3]. Thinking in a different manner, we use these techniques to show specific information only to the human eye while showing different information to a camera. Thus, we can project an image that human eyes can see but that cameras can only capture as an incomplete frame, as depicted in Figure **??** (left). Therefore, the projected light with our techniques produces unphotogenic and unattractive photographs.

Our approach presents images to human eyes by using the afterimage effect produced in the human visual system. We divide the image into smaller parts and project each

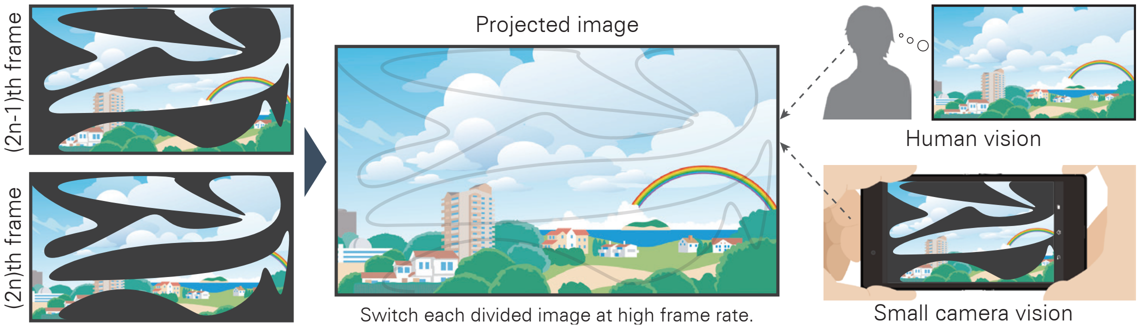

Figure 1.1: System overview of proposed method when projecting a static image. We project an entire image by switching between each divided part of that image at a high frame rate. Unlike cameras, human beings can perceive ("capture") an entire image.

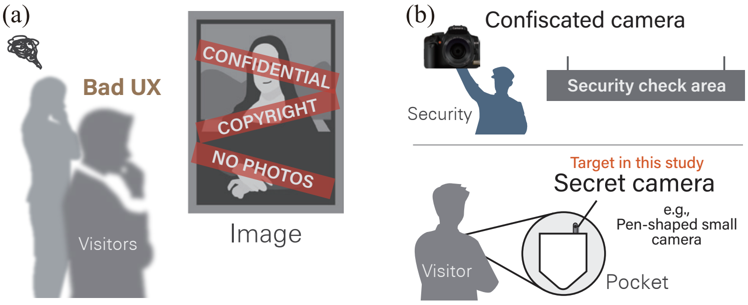

Figure 1.2: Existing methods to prevent secret photography. (a) A visible watermark, which is a simple and effective method to prevent secret photography. However, it creates bad experiences for people because they cannot avoid seeing watermarks when they see the image. (b) Inspection and security are other solutions to the problem of secret photography. However, visitors can illegally photograph using small cameras. The proposed method prevents secret photography in this situation.

part in succession over the same projection periods. By contrast to human eyes, cameras must synchronize the frame period and the shutter timing to capture photos, as shown in Figure 1.3. However, it is extremely difficult to capture an image with a camera that does not synchronize with a projector. In this study, we do not consider long exposure in photographs because a small camera, which is the focus of our system (Figure 1.2), tends to have an insufficient adjustable diaphragm. When people try to take a beautiful photo using a small camera and without blowing up highlights, they have to increase the shutter speed. Therefore, our system works well in this type of situation.

We implemented this method with a projector that projects grayscale images, and then evaluated our system from the perspective of a camera's vision. Furthermore, we report on the feedback given by visitors to a conference [4, 5] at which we demonstrated our method.

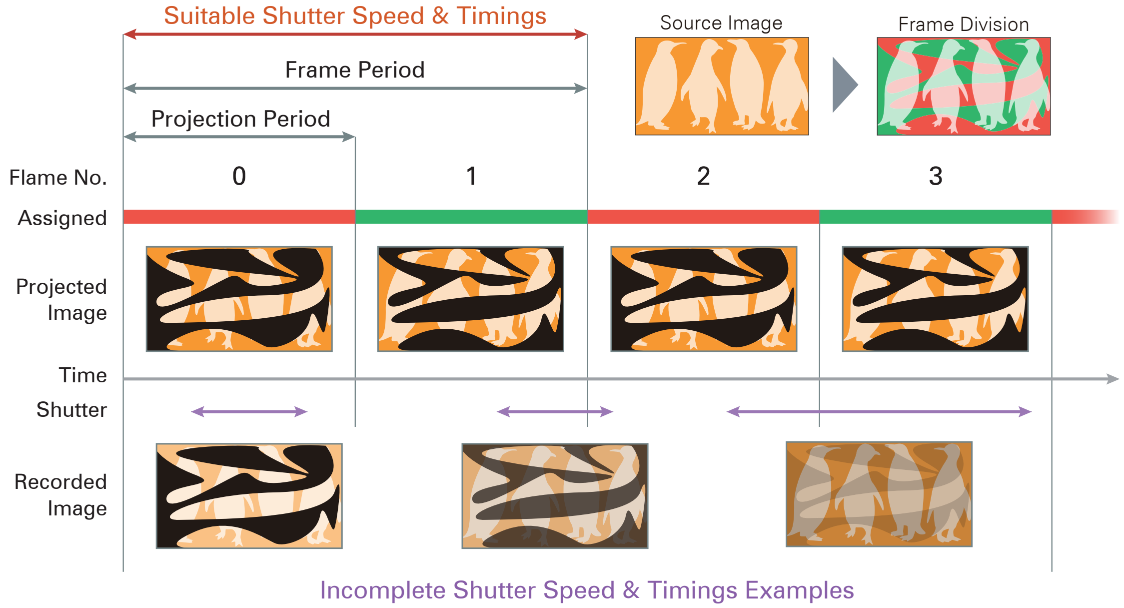

Figure 1.3: Theory and effect of the proposed method. The image is divided into multiple parts, and the parts are then projected in succession. We must synchronize the camera shutter speed and frame period in order to capture the entire image correctly. Please note that colors in a frame-division image only present patterns of divided areas and have nothing to do with the projected color. Right: specifications of the projector for input images and pixel mapping. The input image is the native DMD resolution of 912×1140 pixels. Outputs (projected) image is mapped to WXGA (1280×800 pixels). In the pattern sequence mode, we can project images based on each bit of the RGB input image.

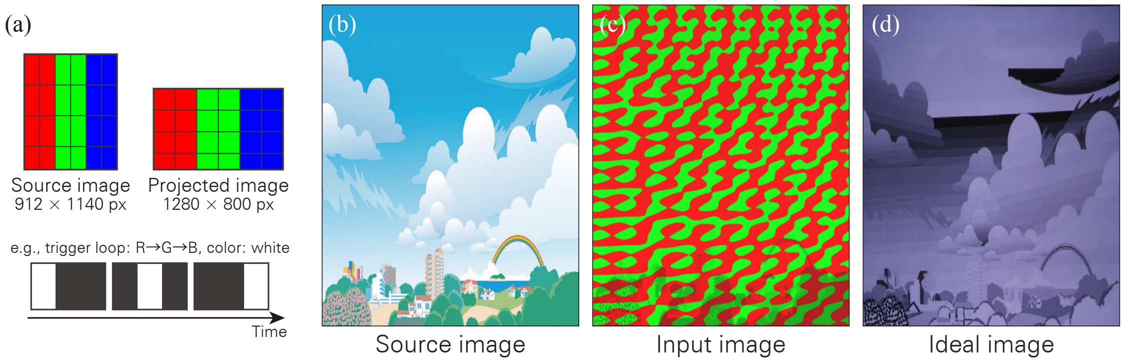

Figure 1.4: (a) Specifications of the projector for input images and pixel mapping. The input image is the native DMD resolution of 912×1140 pixels. Outputs (projected) image is mapped to WXGA (1280×800 pixels). In the pattern sequence mode, we can project images based on each bit of the RGB input image. (b) The original image used for our evaluation. The program generates the image (c) for writing to the projector's internal flash memory. The projector in this experiment displays a 4-bit grayscale image read from (c) using red and green images in different frames. (d) The ideal image perceived by naked eyes with an afterimage effect.

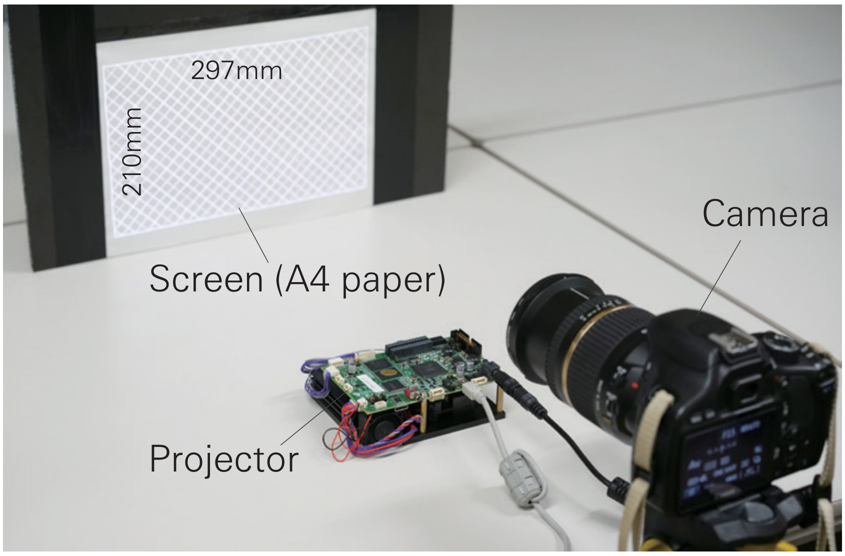

Figure 1.5: Evaluation setup for camera vision. The screen is plain paper and the size of the projection area is 297 × 210 mm.

Chapter 2

Related Work

In this section, we review related work that examines the different characteristics of camera and human vision.

Embedding information in an environment is a major idea of ubiquitous computing [6]. The barcode and QR code are popular means of embedding information because they do not require additional components such as radio frequency identification (RFID) tags. However, even though these types of labels and tags use markers that are visible to both cameras and human eyes, they are not suitable for most environments and are inappropriate for design. Therefore, researchers have tried to develop methods that embed invisible information in the environment.

Several studies have introduced imperceptible on-screen markers. Grundhöfer *et al.* presented a method to detect invisible markers by using a synchronized camera [7]. VRCodes [8] uses a built-in rolling-shutter image sensor in pervasive cameras such as smartphones to detect binary codes embedded in displays. However, the researchers in this study failed to realize that they could simply use an unsynchronized camera instead. Sampaio et al. [2] also presented a method to detect visual codes embedded in images using an unsynchronized camera. Their system could use both rolling- and global-shutter cameras. Visual SyncAR [3] uses digital watermarks on videos to display the camera timecode and employs a system by which animations in augmented reality (AR) can be synchronized with the video. DisCo [9] transmits messages from a display to a camera by modulating the display's brightness at high frequencies. The focus of these previous studies is similar to our own. However, the previous studies mainly examined techniques for producing AR or virtual reality (VR) and not for securing and protecting recordable content.

Chapter 3

Implementation

In this section, we describe our implementation. Our system consisted of a projector, a computer, and a screen.

3.1 Projector

We used one high-speed projector (DLP LightCrafter 4500 EVM[1]; Texas Instruments Inc.). It was controlled by GUI software provided by Texas Instruments, Inc. We prepared input images of 912×1140 pixels that were mapped to 1280×800 during projection, as shown in Figure 1.4 (a). In the pattern sequence mode, we can project 1-bit to 8-bit grayscale images by using 24-bit red-green-blue (RGB) images. Each 8-bit color (*i.e.*, each of R, G, and B) in these images expressed different bit planes. (Please see the web page of the projector[1] for more information about input pattern images.) Using our system, we projected 4-bit grayscale images at 240 Hz with a white light source. The following parameters were set: bit plane selection, output light color, projection period, and exposure period. In our evaluations, the projection and exposure periods were set to the same duration.

3.2 Patterns of division

Source images were divided into two parts by using Processing (ver 3.0.2), as shown in Figure 1.4 (b)-(d). In this study, the "plasma effect" was used as a randomly selected division method. We referred to *Lode's Computer Graphics Tutorial*[2] to create an image division program. Other patterns of division could also be used. Our current system only accepts 2-bit patterns in order to divide input images into two parts.

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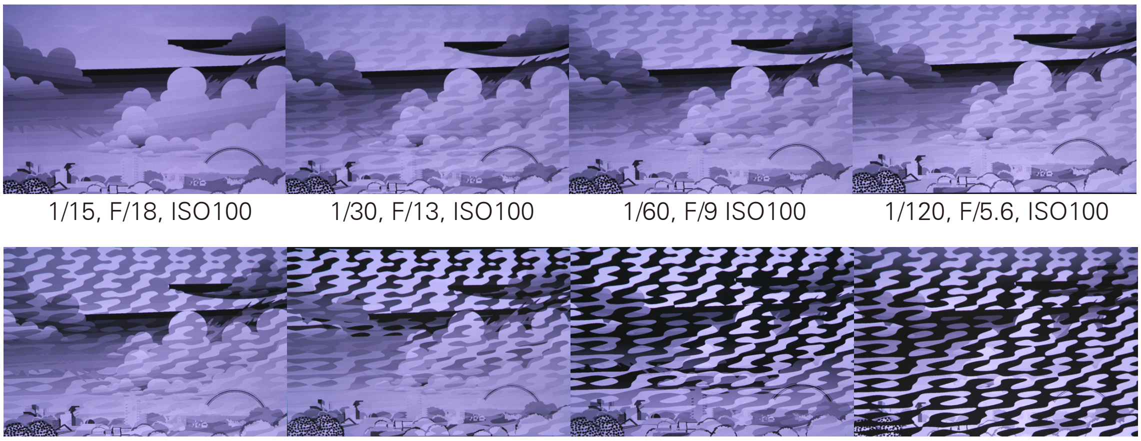
[1] http://www.ti.com/tool/dlplcr4500evm (last accessed Feb. 5, 2021)

[2] http://lodev.org/cgtutor/plasma.html (last accessed Feb. 5, 2021)

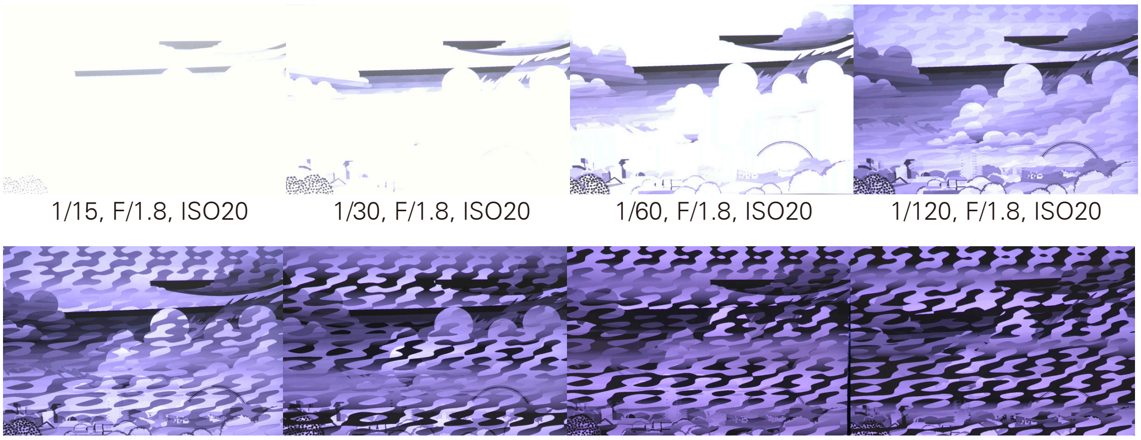
Camera A (Canon EOS Kiss X4 with SIGMA 17-50mm F2.8 EX DC OS HSM)



1/15, F/18, ISO100 | 1/30, F/13, ISO100 | 1/60, F/9 ISO100 | 1/120, F/5.6, ISO100

1/160, F/5.6, ISO100 | 1/250, F/4.5, ISO100 | 1/320, F/4, ISO100 | 1/500, F/3.2, ISO100

Camera B (Apple iPhone 7, with App "ProShot" by Rise Up Games LLC.)
All photos were taken by F/1.8 (this camera has non-adjustable aperture).



1/15, F/1.8, ISO20 | 1/30, F/1.8, ISO20 | 1/60, F/1.8, ISO20 | 1/120, F/1.8, ISO20

1/160, F/1.8, ISO20 | 1/250, F/1.8, ISO20 | 1/320, F/1.8, ISO20 | 1/500, F/1.8, ISO32

Figure 3.1: Images from camera vision. The projection period of each divided frame is 4166 ms (approximately 240Hz).

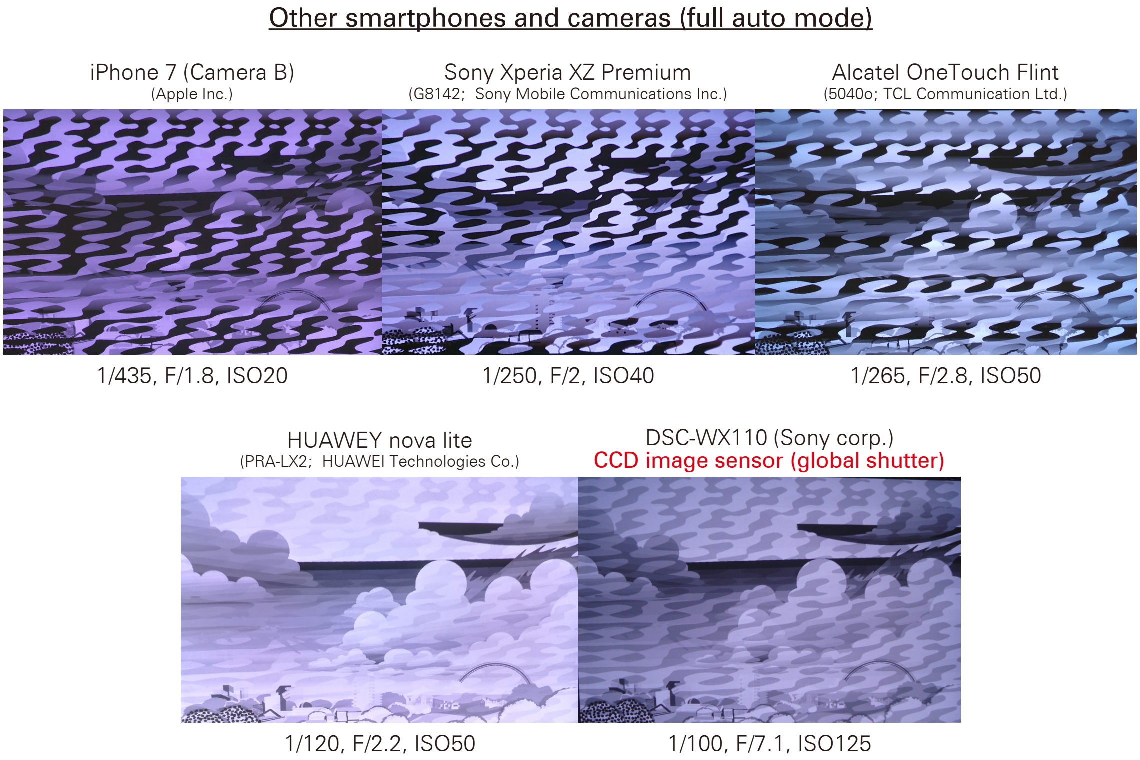


Figure 3.2: Images from other smartphones and cameras with full auto mode of the default camera application. The projection period of each divided frame is 4166 ms (approximately 240Hz).

Chapter 4

Evaluation

We evaluated the relationship between parameters of projectors and cameras. The purpose of the proposed method was to protect projected images or objects from secret photography. Thus, images and information projected on our experimental screen when using our proposed method could not be captured properly by a camera.

4.1 Setup for the evaluation

We first used a digital single-lens reflex camera (DSLR) as a camera vision. The DSLR can control the shutter speed finely and its f-stops can be adjusted to wide ranges. The success of our system depends on the shutter speed of the camera. Therefore, changes in the captured image must be assessed based on the shutter speed. Reducing the shutter speed darkens images, whereas a faster shutter speed makes them brighter. Thus, to investigate the effect of shutter speed while maintaining the brightness of the image, we needed to adjust the image brightness while considering other factors such as aperture and ISO speed by using DSLR.

Next, a smartphone (iPhone 7; Apple Inc.) was used to verify the effects of our system in an actual situation involving secret photography. We took photos while changing the shutter speed. Then, we also took photos using other smartphones. Consistent with an actual photo-shooting situation, pictures from other smartphones and cameras were captured in default mode (full auto) using the pre-installed camera applications in those devices. Our experimental setup is shown in Figure 1.5.

4.2 Result

Results are shown in Figure 3.1 and 3.2. Based on the results from camera B and other smartphones, we can see our system successfully altered photos. The camera with the global shutter also captured incomplete frames (Figure 3.2, DSC-WX110; SONY corp.). For camera A as shown in Figure 3.1, when the shutter speed decreases to less than 1/30, the DSLR can capture the projected image correctly. However, photos taken by the smartphone at this shutter speed result in blown-up highlights such that people cannot see the projected image. When the shutter speed of the smartphone is increased, highlights become clear, then the effect of our system appears in the photo.

Chapter 5

Applications

5.1 Protection of screen content

The main purpose of this study was to develop a technique that prevents secret photographs from being captured. It can be applied, for example, to secret slides in a presentation, that is, for slides containing information or images that a speaker wishes to protect from being photographed. With our system, presenters do not need to warn audience members about taking photos of presented slides.

As another example, our system can be used to protect photos for sale in theme parks, as shown in Figure 5.1. As is well known, a system currently exists that takes photos of passengers during an attraction or event, such as when riding a roller coaster. Photos are previewed on a screen near the exit and passengers have the option to purchase them or not. However, passengers can also take photos of that preview screen using their smartphones. With the proposed method, we can prevent passengers from taking a photo of the screen. We can use the silhouette of a character as a pattern of division, which may attract people who try to take photos.

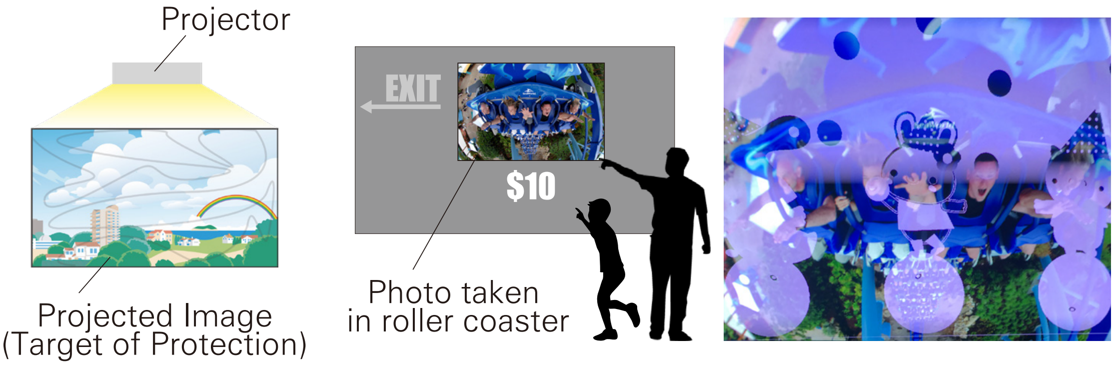


Figure 5.1: An application example: Protecting photos of attractions in a theme park. (Photo of the roller coaster by Ted Murphy, CC BY 2.0)

5.2 Protective illumination

The proposed system can be used not only as an image projector but also as an illumination system. For example, the system can be installed in an art gallery as a kind of spotlight, as shown in Figure 5.2. Our system projects a circular spotlight onto artwork when people view them. However, from the secret camera, the projected light produces a blurred image.

Figure 5.2: An application example: In the museum, we can use our system for protective illumination.

Chapter 6

Discussion and Future Work

6.1 Robustness of our system

For a more robust system, we must make a shutter speed of the secret camera faster than the threshold defined by projection speeds. If the shutter speed is slower than that threshold (*e.g.*, when using long-term exposure), the secret camera can capture an image. Therefore, high-specification cameras such as DSLR can evade our system because they can close the f-stop to reduce the shutter speed and avoid blowing up highlights. However, because we can verbally warn people who try to use such cameras and our system can prevent them from using recordable cameras, particularly small devices that are hidden, we consider protecting content by combining warning by human with the capabilities of our system.

Currently, our system can only show a static image. However, it also seems to be very difficult to record a video when a projected video is being displayed. This is because the camera must be synchronized with the timing of video frames and have the appropriate shutter period to capture the entire video. Furthermore, by changing the projection period randomly, we can ensure our system prevent video reconstruction which is by multiple captured photos.

A video-interlacing technique included with our system also divides an image into two parts and shows them in the proper order. It smoothes the image without increasing the amount of image transmission. In actuality, capturing complete photos of an image shown by an interlacing display (*e.g.*, CRT display) is difficult. However, such images are easier to restore than the images shown by our method because the division pattern of the interlacing display has well-known regularity and they divide images into many small parts. In our method, it is more difficult to restore because we employ random division and each area is large. We will explore division pattern optimized for each image to ensure our system as future work.

6.2 Quality of the display

The brightness of each pixel diminishes because we should project images using shorter duration than in a normal projection. When we divide images into n areas, people perceive images having $1/n$ of the original brightness. Employing a projector that has high brightness, high projection speed, and high resolution enhance the quality of the screen.

6.3 Flicker perceived by the human vision

As guests of our demonstration commented at the previous conference [4], when a person's viewpoint of a screen was altered by eye saccade, they tended to perceive flicker. Other guests reported that they could perceive division patterns when they viewed our screen through a waving hand in front of them such as via steganography as proposed by Yamamoto *et al.* [10]. Tradeoffs thus exist between the strength of the system's resistance to flicker and an acceptable shutter speed in terms of slowness. When we use a low-speed projector, people also perceive flicker. Our system may not be suitable for extended viewing of media, such as of movies in cinemas. We will explore division pattern optimization for images so that flicker can be removed.

Chapter 7

Conclusion

In this study, we presented a new method to protect projected images and other information (*i.e.*, “content”) by examining the different characteristics of small cameras and the human visual system. Our method can protect various items from being secretly photographed using small cameras. Security persons can prevent successful captures of secret photography by using large cameras such as DSLR. We combined the protection capabilities of our system with the human giving oral warnings. Our method may not be able to prevent secret photography by 100% of the time, but it is one solution that reduce the possibilities of secret photography.

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