Optical Camouflage III: Auto-Stereoscopic and Multiple-View Display System using Retro-Reflective Projection Technology

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ABSTRACT

This paper presents a new type of optical camouflage system based on the retro-reflective projection technology. Retro-reflective projection is a method used to create augmented reality that combines the virtual world with the real world. The conventional model of an optical camouflage system consists of a retro-reflective screen, a projection source and a beam splitter. In such a setup, the user needs to observe an object covered with the retro-reflective screen through a single viewpoint. This is called a monocular system. In our new setup, our aim is to construct a system that has multiple viewpoints by applying a novel projection array system. We will describe the method with which this projection array system is achieved using one projection source, the configuration of the system, and the trade-offs of the system. In addition, we will describe an application of our system in a car. The installed system makes the backseat virtually transparent, allowing the driver to see the blind spots at the rear when reversing the car.

KEYWORDS: Retro-reflective projection technology, auto-stereoscopic, multiple view display, optical camouflage.

INDEX TERMS: I.4.0 [Image Processing and Computer Vision]: General—Image displays; I.4.9 [Image Processing and Computer Vision]: Applications

1 INTRODUCTION

Retro-reflective projection technology (RPT) is a method used to create augmented reality that combines the virtual world with the real world[1]. This method is often used to make an object virtually transparent. A basic RPT system consists of a projection source, a half mirror, and a retro-reflective screen which reflects incoming light in the same direction. In such a setup, the half mirror is placed between an object, covered with the retro-reflective screen, and the observer. The projection source and observer's eye position are located in conjugated position with respect to the half mirror. When an image behind the object is captured and projected onto the screen, the object will appear virtually transparent to the observer.

RPT has been used in previous optical camouflage systems. In these systems, since there is only one projection source, the observer needs to look at an object covered with retro-reflective material through a small hole in order to experience the optical camouflage effect. This is called a monocular system. While it is possible to construct a binocular system by adding a second projection source, the physical size of a projector has been, for a long time, a limitation in terms of practical implementation. The emergence of high-resolution and high-brightness projectors provides a new opportunity to create such a multi-viewpoint system using a single projection source.

In this paper, we explore a novel multiple projection technique whereby, instead of using a number of projectors, a single projector is combined with a lens array to achieve multiple viewpoints(Figure 1). In addition, we aim to build an application for this new type of optical camouflage system.

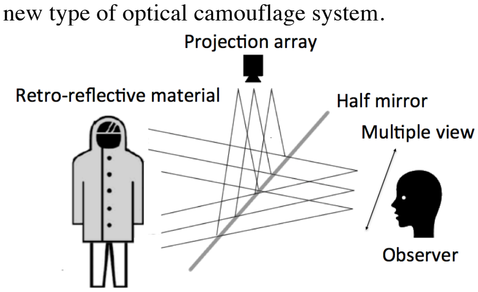

Figure1.Optical camouflage system which has multiple viewpoints

2 RELATED WORK

Optical systems using RPT is mainly classified into three types; head-mounted, handheld, and standing systems. In head-mounted display systems, the projector follows the observer's viewpoint, and hence image projection corresponding to the observer's viewpoint movement, can be achieved. In handheld system, it mainly consists of a small projector and a small camera. As a result, it is highly portable and easier to implement[2]. In standing systems, besides the basic optical camouflage system, Yoshida et al proposed a haptic and stereoscopic display setup[3]. In their system, they achieved a projection array using an LCD and a lens array.

Our system is classified as a standing system. Our system is different from the related work in that it achieves multi projection using only one projector instead of using LCD, and also it captures images from the real world instead of using computer graphics.

3 SYSTEM

3.1 Optical setup

Our approach is based on the basic optical camouflage system, and optical system proposed by Yoshida et al. In our setup, the system consists of a projector, a field lens, a lens array, a half mirror, and a retro-reflective screen. These optical parts are arranged as shown in Figure 2. The figure shows the overhead view of our setup:

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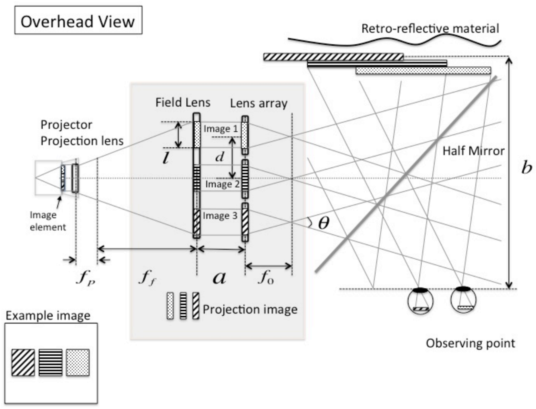

Figure 2. Multiple viewpoint system for retro-reflective projection technology.

Where f_p is the minimal focal length of the projector, f_f is the focal length of the field lens, and f_o is the focal length of the lenses which make up lens array. ***a*** is the distance between the field lens and the lens array. ***d*** is the distance between the axes of the lenses in the lens array. Projected light from the projection source forms an image on the field lens, and ***l*** is the size of the projection image. $\boldsymbol{\theta}$ is the view angle of each lens in the lens array.

First of all, to make light projected from the projection source collimate, we use the field lens. The following expression holds true for this configuration. $R=f_p+f_f$. Where ***R*** is the distance from the projector lens to the field lens. In this setup, we assume that the optical axes of the projector and field lens are coincident. Field lens is set parallel to lens array. Each of the lenses making up the lens array works as a single projection lens. As a result, the number of lens in the lens array is equivalent to the number of projection source and hence viewpoints. Image from a projection lens is projected onto the retro-reflective screen using a half mirror. The following expression holds true: $L=lb/f_0$, $l=l_0f_f$, $\theta=2\arctan(L/2b)=2\arctan(l/2f_0)$, Where ***L*** is the size of the projected image observed by the observer. $\boldsymbol{\theta}$ is the view angle of the projection lens. l_0 is the size of the image on the picture element in the projector.

3.2 System characteristics, Trade-offs

Our system has the following characteristics. In any multiple view-point system, crosstalk effect is a typical problem especially when LCD is employed as a projection source. This is because light from the back light diffuses onto the display surface. On the other hand, in our system, projected light from the projector is collimated by the field lens, so there is low crosstalk effect. At the same time, collimating projected light improves energy efficiency compared to using LCD for multi projection.

In our setup, trade-offs are described in terms of variable parameters of the system. In this system, variable parameters are effective aperture and focal length of lenses. In this section, we fix the projector's specification in order to focus on the lens setup. Table 1 shows the effects and changes in the system, when one parameter increases from its default value.

4 Discussion on the System

As we mentioned in the previous session, our system has trade-offs. Users need to carefully choose the lens's radius and focal length for different uses.

Main limitation of our system at this time is that the resolution of the image. Since our system employs one projector and it projects the number of images equaling to the number of the lenses in the lens array, the resolution of the projector becomes crucial. However, this can be solved by using a projector which has high resolution. Another aspect that needs to be taken into consideration is parallax difference. In our setup, the projected images are captured from the four cameras. In theory, if the projected images on the retro-reflective screen are at infinity or far away from the cameras, the projected images will seamlessly match the background environment. However, in practice, the infinity condition is not possible, hence the parallax difference needs to be taken into consideration for every setup. These can be the future work of this research.

Table 1. Effect of changes in the system

	Diameter(increase)	Focal length(increase)
Field Lens	Observable area (increase) System size (increase)	Distance between Field lens and a projector (increase)
Lens array	Resolution of resolution of observed image (increase) Spacial density of view points (decrease) View angle (increase)	View angle (decrease)

5 Application

To explore a real use of the system we specifically built a setup to fit within a car. Our aim is to make the backseat virtually transparent, allowing the driver to see the blind spots at the rear when reversing the car(Figure3). In this application, it was clear that the system had multiple view points, but in terms of usability, improvements are still needed to help guide the driver to observe.

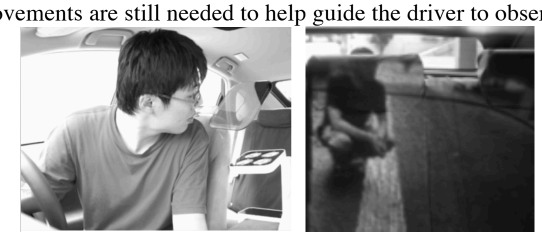

Figure 3. (Left) Driver's experience: driver was able to see image (Right) which was captured by the cameras behind the car.

6 Conclusion

In this paper, we proposed an auto-stereoscopic and multiple-view system using retro-reflective projection technology. The proposed optical system achieves multi projection source using one projector. We described the configuration of the system and the trade-offs of the system. In addition, we applied our proposed system to the car.

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