Demo Proposal: Screen-less Head Mounted Projector with Retro-tranmissive Optics

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Abstract: A prototype on the test bench of the novel Head Mounted Projector will be presented. While this HMD is the projector based one, it does not require the external screen. The optical system is mainly the combination of the projection optics and the "retrotransmissive" screen in front of the user's eye. The "retrotransmission" is a novel and key notion to enable this type of HMD. As the result, the optical structure of this HMD is not similar to any existing one.
To prove the operating princple of this HMD, a simple prototype using the rotating array of conercube prisms, a beamsplitter and a projector is developed and will be demnstraited. The observed image has enough resotution for the user to read the characters in 6 points.

Key Words: Virtual Reality, Augmented Reality, Head Mounted Projector, Head Mounted Display, Retroreflector

1. Introduction

Head mounted display can be classified into those which produce the false image and which forms the true image. The former type started by using the convex lens between the eye and LCD panel. Soon later the concave mirror is applied to realize the wider field of view. The latter type is the head mounted projector that forms the true image on the screen object.

Initially, the claimed merits of head mounted projector were that the object in any shape can be used as the screen shape since the image distortion is cancelled by placing the exit pupil of the projector conjugated with the viewer's pupil, and that the projection optics is easier to design to obtain the wide field-of-view compared with the optics that forms the false image [1]. By introducing the retroreflector as the screen, the other merits were added such as the stereoscopic separation and the usage of the smaller projector due to the high reflection gain [2-4]. Recent research introduced the convex mirror to enable very wide field-of-view [5].

On the other hand, the defect is that the projector requires the external screen. To eliminate this, the head mounted projection display equipped with the built-in screen was realized by introducing the freznel convex lens between the beam splitter and the retroreflective screen [6].

In this paper, the false image projector without the need of screen will be proposed by introducing notion of the retrotransmissiion. Though the optical element that can be called as the retrotransmiter has developed sporadically for some specific optical apparatuses [7-9], they were used to form the true image and there is no example to utilize the true-false image conversion.

The retrotransmission will be abbreviated as RT, and retroreflection as RR in this article.

2. Retrotransmission

2.1 Factors to Fold the Space

Mirrors fold the space in plane-symmetry. This is cased by the function to flip the incident ray in the direction of normal vector. Both the real object and the true image formed by projector on this side of the mirror are observed as the false image on the far side.

The retroreflector (RR) also flips the incident rays in the direction of the normal vector, however, it forms the true image at the same place as the original one. The difference from the mirror is that the RR flips the direction of ray also in-plane. Since this in-plane reflection causes the folding of space in plane symmetry as well, the space is folded two times. As the result, the space seems not to be folded. Another function of the reflection in-plane is that the convergent rays to form the true image is converted to the divergent rays that forms the false image, and vise-versa.

In Figure 1, x(-1) corresponds to the case where the ray is flipped and x(+1) to no flip, in the normal direction and/or in- plane. The cell (raw, column)=(1, 1) means the transparent plane that does not change the ray at all. (1, -1) is the mirror that folds the space and convert the true image to false image. (-1, -1) is the RR. It does not fold the space and form the true image of the real object and/or true image formed by the projector since it converts the divergent and convergent rays each other.

The last cell or (-1, 1) does not reflect the ray in the normal direction but reflects it in-plane. Authors define this effect as the RT. As explained for the case of RR, the true image forms the true image again. The difference is that the position of this true image is at the plane symmetric to the original one.

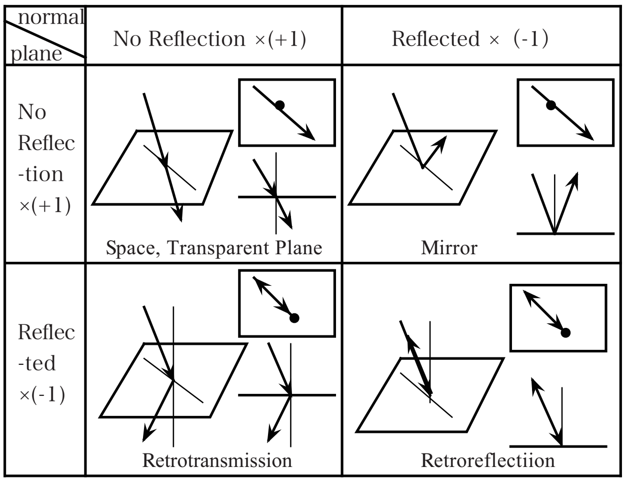


Figure 1: Reflection, Retroreflection, Retrotransmission

2.2 Principle of False Image Projector : True-False Image Conversion

When the true image is formed across the plane, the pencil of ray is interfered and the image is not formed. In this paper, the original true image will be called as "to-be-true image".

In the case of the mirror, the to be true image become a true image at the projector's side of the mirror. In the case of RR and RT, the to-be-true image became the virtual image since these materials exchange the convergent and divergent rays by the reflection in the plane. This function to change the to-be-true image to the false image will be called as "true-false image conversion" in this paper. In the case of RT, the true image is formed at the plane symmetric position of the to-be-true image. In the case of RR, the true image is formed at the original position.

Figure 2 shows the structure of the proposed false image projector. As compared to the normal projector that forms the true image, the viewer can watch the false image at the projector's side of the RT material in the proposed optical system, by the space flipping and the true-false image conversion.

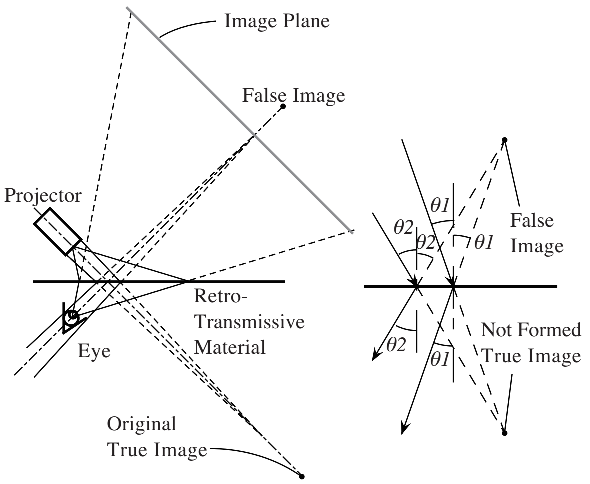


Figure 2: False Image Projector with Retrotransmissive Material

2.3. Possible Structure of Retrotransmissive Material

In this section, the optical structure to realize the retrotransmission will be discussed.

The first way is the combination of the RR and beam splitter (Figure 3 Left). A semi-transparent RR can be realized by placing the small RR areas discretely, and its combination with the beam splitter provides the RT function. The RR reflects the ray both in-plane and in the direction of the normal vector. The beam splitter as mirror flips back the ray in the normal direction. Thus, the RR is changed to RT by cancelling the reflection in the normal direction. To obtain the accurate retro-characteristics, the glass beads with the refractive index 2.0 or small corner cube prism can be applied. When the beam splitter is placed outside, it seems similar to the pancake window. If it is inside, while it seems similar to the head mounted projector with modified RR screen, the difference is that the projector is placed between two optical elements.

The second way is to realize the RT directly by the corner mirrors. There is already a realized example of the micro-corner-mirror array [8].

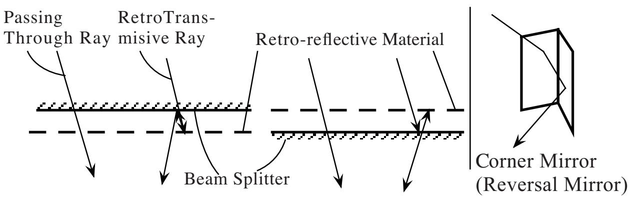


Figure 3: Structure of Retrotransmissive Material

Figure 4 shows the advanced example of the realization. The upper face of a plate works as the beam splitter by the reflection coat. The lower face has micro corner cube prisms discretely. The right figure shows the same structure is inside the plate material.

As the other structure using the reflective element, micro mirror array on the concentric circle can be used for the projector with a very small exit pupil. As the examples using the refractive element, the afocal lens array[7], the Grin rod lens array [9] etc. can provide the RT, however, the refractive element has the defect to cause the chromatic aberration as well as the defects that the entrance angle, range of the object and image point is very limited.

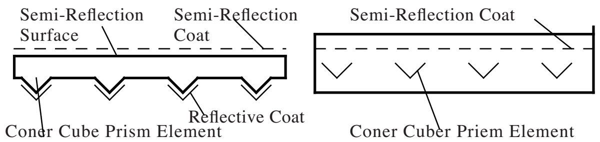


Figure 4: Example Structure of Retrotransmissive Material

3 Curved Retro Surface

The false image projector with RT material could be extended to have wider field-of-view similar to [5] with the convex mirror. Figure 5 shows the system with expanded field-of-view by introducing the curved mirror. The curved half-silvered mirror was placed outside in the left figure. The reflection surface fasces to inside and works as the concave mirror. The projector is folded to inside by the RR, and the rays are observed via convex mirror. Right figure shows the case where the beam splitter is inside. While the right figure seems to similar to [5], these two can be understood to have the same function by the notion of RT.

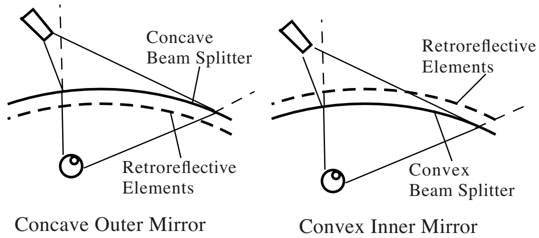


Figure 5: Curved Retrotransmissive Plane

4. Prototype System

A prototype were realized using the commercially available materials. To evaluate the image watched by human eye, a camera with the similar radius of iris as human eyeball (2 millimeters) was placed in plane symmetry to the projector. The focus of the camera was set at the designed image plane or the folded image plane of the projector. The camera was Pixelink PL-B774F (1600x1200 pixels, 1/2 inch CMOS) with a single focus lens (f=25 millimeters, F1.4-16C, FOV=14.6 degs horizontal, both sides). RR was the corner cube prism from edmund optics (confusion angle=10 archminutes, diameter=7.16 millimeters), the projector was Canon 3400MP (1024x768 pixels, projection distance 1.1-8 meters, horizontal projection angle 15 degrees, nominal).

The structure of this prototype is shown in Figure 9. The rays from the projector pass through the beam splitter and reflected by RRs. Then the rays are reflected by the beam splitter and reach the camera. The RT plane was the viewer's side of the beam splitter.

Two arrays of the corner cube prisms were attached to a transparent acrylic disk. An electric motor rotated this disk so that the field of view is dynamically covered by the corner cube prisms.

Figure 10 shows the observed images. A propotional font, Courier New was used as the sample image. The size of font were 48, 24, 12, 9 and 6 points.

When the projection distance was set to 6 meters, the users were able to read all the characters, even in 6 points. As the image plane became closer to the user, the blur increased as explaned in eq (3). For example, at 3 meters, the readable limit was 12 points and 48 points at 1 meter. The result of another experiment to observe a vertical line showed the amount of the blur matched well with eq (3).

Because the corner cube prism were not set accurately to face to the center of the projector's exit pupil, the brightness of the observed image was not flat over the field of view as shown in Figure 10. Also the doubled image appeard in part because of the warp of the rotating disk.

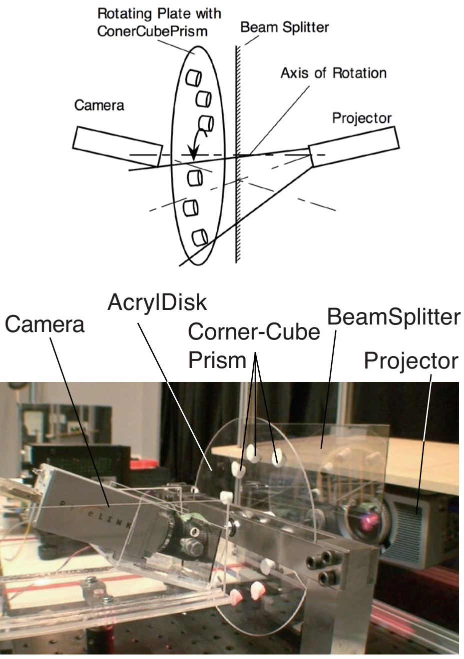
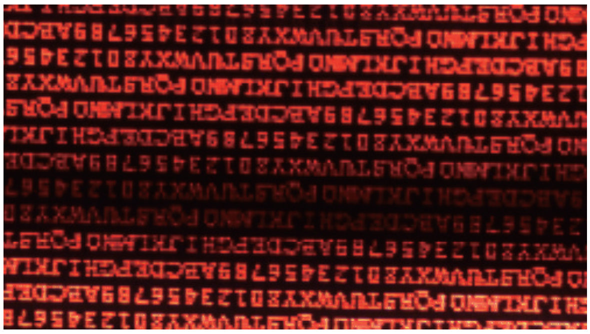


Figure 9. Prototype System.



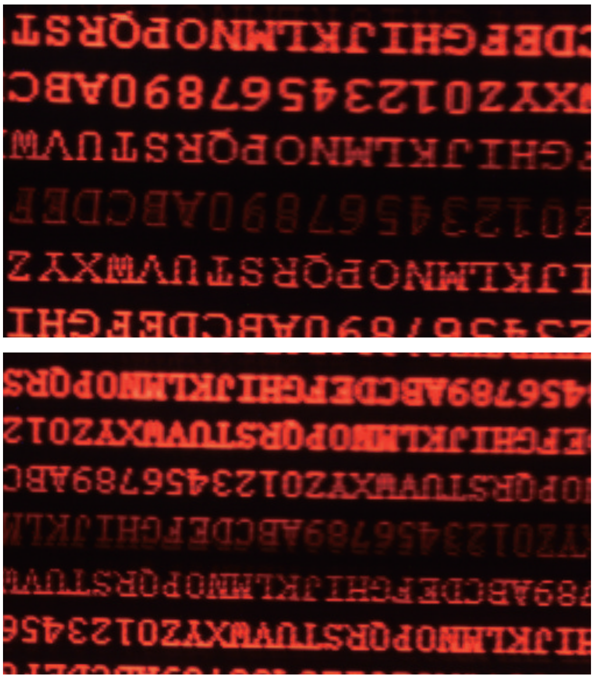


Figure 10. Observed Image (Top: Font is in 24 point, Middle: 12 point, Bottom: 6 point (9 pixels by 9 pixels).

7. Conclusion and Future Work

The notion of RT: retrotransmission was introduced and two functions of it, the space folding and the true-to-false image conversion, were explained. The false image projector was proposed. Several example structures to realize the RT were discussed, and the curved RT to obtain the wide field of view was also discussed. Thus the wider potential realization and extension were descrived, apart from the extension of the head mounted projector using RR, by introducing the notion of RT. It is easier to design and produce the projection optics with the wide view angle than the case of optics that forms the false image. The false image projector could potentially inherit this merit and does not require the external screen.

Finally, a prototype using the large corner cube prism on the rotating disk was constructed. The resulting image at the distance of 6 meters were clear enough to read the text in 6 points. This is close to the resolution of the projector, and the equivalent eyesight was 0.6.

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