Comparison of Material Combinations for Bright and Clear Floating Image by Retro-reflective Re-imaging Technique

Yutaka Tokuda, **Atsushi Hiyama***, **Michitaka Hirose***, **Tim Large****

RCAST, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
* The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
** Microsoft Applied Sciences Group, 1 Microsoft Way Redmond WA, USA

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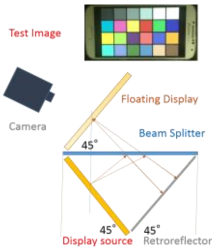

Fig. 1 Experimental Setup

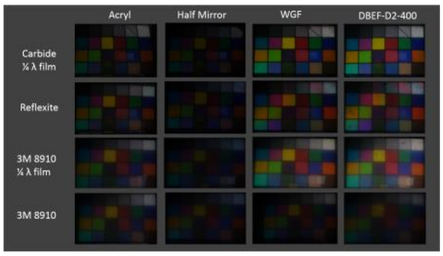

Fig. 2 Results (Row: Retroreflector, Column: Beam Splitter)

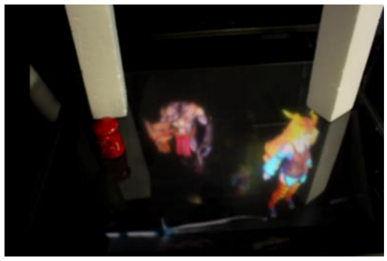

Fig. 3 42-inch Floating Display

ABSTRACT

We investigate a solution to create clear and bright floating images from LCD display by comparing 16 different kinds of retro-reflectors and beam-splitters for a pseudo-phase-conjugation-effect. We found a reflective polarizer film can enhance the brightness and corner-cube array retroreflectors can create clearer results than glass beads type for LCD.

1. INTRODUCTION

In spite of the emergence of 3D tracking sensors, such as Kinect, Leap Motion, Senz3D, etc., current flat rigid 2D displays do not allow users to reach-through and directly touch 3D contents in the same physical space. On the other hand, 3D displays can create a floating image but can cause fatigue to users owing to the mismatch of focus and accommodation. Hologram can solve this problem but it is still challenging to scale size up with full color and dynamic contents.

Recently, several researchers and companies have proposed alternative solutions to make real floating images from regular 2D displays. There are mainly two ways: Lobster Eyes' optics [1,2] and Pseudo phase conjugation optics [3,4]. Lobster Eyes' optics can create sharp and bright floating images from original displays, but it is expensive and difficult to scale the size at a current micro fabrication level. In contrast, pseudo-phase conjugation optics only require commonly available optical elements: retroreflectors and beam splitters. Since both elements are cheap and available in a large size, many researchers have utilized this technique to create static floating images [3], and dynamic LED based floating displays [4].

However, floating images created by pseudo-phase conjugation optics are generally more blur and darker than Lobster Eye's technique because of the two facts: converging rays must take a longer optical path between display sources and re-imaged points and only a fraction of them can reflect and pass through at surfaces of beam splitters and retroreflectors before re-imaging.

To investigate these problems more, we compared 16 combinations of retroreflectors and beamsplitters commonly available in the markets and filtered out the optimal condition to create a clear and bright floating image. In particular, we focused our target display source to LCD displays, which have not been studied well in previous research.

2. Optimal Condition for Pseudo-phase-conjugation

2.1 Experiment

In this experiment, we compared floating image's brightness and color clearness of the sixteen combinational results deploying four kinds of retroreflectors with four kinds of beamsplitters to investigate the difference at pseudo-phase conjugation optics. Retroreflectors are selected from two copy-right-logo-free corner cube array types (Nippon Carbide Nikkalite Crystal Grade laminated with ¼ λ film , Reflexite Shadow Logo version corner cube retroreflector) and one glass beads type(3M 8910) with or without ¼ λ plate. Four kinds of Beam Splitters are standard Acryl plate, Half Mirror (30% pass), AsahiKasei Wire Grid Film (WGF), and 3M Dual Brightness Enhancement Film (DBEF-D2-400). Fig.1 shows our experimental setup. We utilized a Samsung Galaxy S4 (5.0-inch, 441 PPI, Super OLED) as a display source and showed a color test image as a target. To record a floating image of sixteen combinations, we used Sony RX100II with ISO 400, 1/30 shutter speed and F3.5 in a dark room of 39 lx. To measure relative brightness (cad/m^2) loss rates of floating image to display source, we used IWASAKI Quapix Lite Software with SmartPhone Sony Xperia Z1 and measured a white image on the Galaxy S4 display.

2.2 Result

Fig. 2 shows our results of floating images. The row is a list of retroreflectors and the column is a list of beam splitters. Among beam splitters, reflective polarized kind of films (WGF and DBEF-D2-400) have the brightest results except 3M 8910. This is because reflective polarized films can effectively reflect S-polarization state ray to the retroreflector and corner-cube array's surface reflection or two passages of ¼ λ plate can change the S-polarization state to P-polarization state in order to transmit through the beam splitter. DBEF-D2-400 shows the brightest result overall and WGF follows. Acryl plate shows brighter results than Half Mirror.

Our brightest measurement result says that Nippon Carbide(+¼ λ Film) + DBEF and 3M 8910(+¼ λ Film) + DBEF are the brightest combination with 41.9% usage of original display brightness. The second brightest combination is that Reflexite with DBEF, Nippon Carbide(+¼ λ Film) + WGF and 3M 8910(+¼ λ Film) + WGF with 32.6% usage of the display brightness. Although a ¼ λ film with a reflective polarized film can work for retro-reflectors which do not change polarized state at retro-reflection, we checked it cannot increase the brightness for Reflexite which causes polarization rotation at each surface reflection of corner cube array.

As for a clearness of colors in a dark room, we found Carbide + DBEF and Carbide + WGF are the best. Reflexite with DBEF and WGF are the second. These are all corner cube type retro-reflectors. Glass beads type 3M 8910 shows more blur floating images compared with those. To verify the visibility under the lighting condition, we further compared the four brightest combinations found in this experiment at the next section.

3. Visibility under Lighting Condition

3.1 Clearness

Fig. 4 shows the result of floating images (bull's eyes) with four brightest combinations from the previous experiment under the lighting condition of 107 lx. DBEF-D2-400 produces lower contrast result than WGF owing to the diffusing layer and reflection of the lighting. To avoid this lighting reflection, we tested Nitto Denko APCF film with polarization film and found a clearer result even at 42-inch TV (Toshiba Regza 42J8) with 700 cad/m^2 as Fig. 2 shows. Carbide film produces the better clearness compared with 3M 8910. This is because corner cube type's micro array structure is normally more organized than glass beads during the production process and glass beads likely include a random size of glass beads in a more disorganized manner.

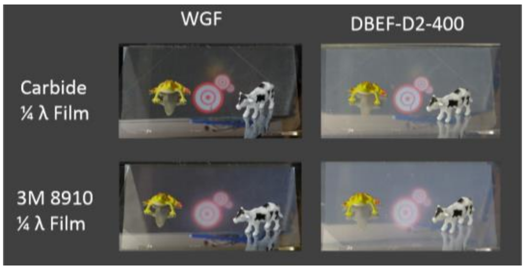

Fig. 4 Result under Lighting Condition

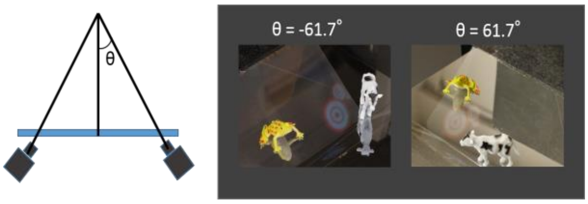

Fig. 5 Result of Viewing Angles

From these results, the optimal combination to create floating image with pseudo-phase conjugation optics is Corner Cube Type retro-reflector with ¼ λ film and reflective polarization film such as DBEF (in a dark room) or WGF (in a lighting room).

3.2 Viewing Angle

Fig. 5 shows result of floating image created by WGF and Carbide film, which are recorded at 61.7 degrees away from the center of the line at left and right side. Although the image part is missed at the side edge of the retroreflector and it is more blur than image captured at the center(Fig.4), we can still identify the floating image.

4. Conclusion

To explore the limitation of pseudo-phase conjugation optics in order to make clear and bright floating image, we compared sixteen different combinations of retro-reflectors and beam splitters. We found reflective polarization film can enhance brightness of floating image and especially corner cube type retroreflectors with ¼ λ film can form the clearest and brightest floating images among market available materials for LCD displays.

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