A Novel Optical See-Through Head-Mounted Display with Occlusion and Intensity Matching Support

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Abstract. In an augmented reality system, Mutual occlusion and intensity matching of real and virtual environment enhance the user's feeling that virtual objects truly exist in the real world. Aiming at the attribute of conventional optical see-through HMD which cannot present mutual occlusion and intensity matching correctly, we propose a novel display design with mutual occlusion and intensity matching capabilities. An 8-bit gray level XGA LCD, by which mutual occlusion and intensity matching be accomplished is used as the addressable filter in our design. Furthermore, with our optical system, a viewer can simultaneously observe both outside scene and a pattern on the LCD panel in focus. Experimental results show that our novel design can integrate more seamlessly a virtual object in a real scene.

Keywords: optical see-through HMD, addressable filter, Augmented Reality.

1 Introduction

Augmented reality system allows a user to work with and examine the physical world, while receiving additional information about the objects in it. There are many target application areas of augmented reality such as computer-aided surgery, repair and maintenance of complex apparatus, entertainment, teaching and so on. In a typical augmented reality system, a user's view of a real scene is augmented by superimposing graphics on the view. Mostly, optical see-through (OST) or video see-through (VST) devices are used to be AR applications [1], [2], [3], [4], [5], [6], [7]. In this paper, we are proposing a novel OST Head-Mounted display (HMD) that is capable of mutual occlusions and intensity matching correctly.

Fig. 1 shows a typical configuration of an OST-HMD. It works using an optical system connects to PC. Rays from real scene go through the system and are combined with rays from computer generated image. Finally, the synthetic image is seen by user. Compared with VST-HMDs, OST-HMDs have relatively simple structures and they preserve the real image as it is without any degradation. However, conventional optical see-through displays have some significant disadvantages, as depicted in previous literatures [1], [2], [3], [4], [5]. One of main disadvantages is the synthetic objects always appear as semitransparent ghosts floating in front of the real scene so that mutual occlusion of the real and virtual environments cannot be displayed correctly. The other is, it is hard to achieve an intensity matching between real and

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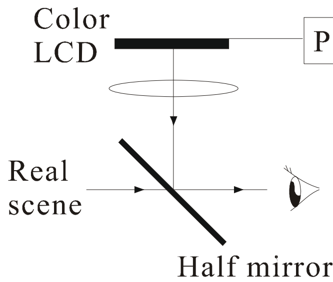

Fig. 1. A typical configuration of an OST-HMD

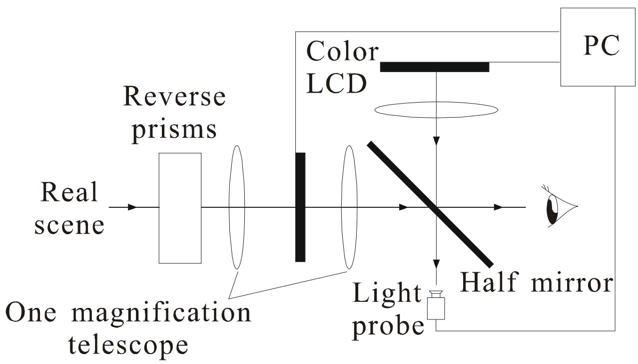

Fig. 2. A typical configuration of an OST-HMD presented previously

virtual environments. To attack the above problems, we propose a novel display design.

2 System Configuration

As depicted graphically in Fig. 2, an OST-HMD presented previously consists of 3 systems and a half mirror. The systems are real scene display system, virtual object display system and intensity matching system, respectively. In real scene display system, a telescope with one magnification is used and an addressable filter is set in it. Our addressable filter is no more than an 8-bit gray level XGA LCD, which replaces the black-white LCD in Kiyoshi's system [2], is the right device to realize mutual occlusion. The virtual object display system consists of a LCD displaying computer-generated objects, and a battery of lens as an ocular. Further, a light probe is employed in the intensity matching system. The half mirror, as an optical combiner [2], [3], [4], blends part of real scene's rays with synthetic images.

However, the optics shown in Fig. 1(b) introduces a viewpoint offset as in [3] along the optical axis, and the long body of telescope makes the HMD uncomfortable to wear. Due to the disadvantages of telescope optics, we redesigned the optics as shown in Fig. 3 based on Kiyoshi's ELMO-4 [4]. Note that three mirrors are employed to change optics of telescope. Let's consider ray paths of our HMD. Firstly, rays from real scene get to a double-face mirror and reflect on it. The reflected rays called real-scene rays then reflect again on mirror 1 and go through the object lens. After one more reflecting on mirror 2, the rays go through the XGA LCD and get to a half mirror. Then parts of rays reflect on the half mirror, and the others go through it to be got by light probe. Virtual object is displayed by color LCD, ant its rays called virtual-image rays reflect on mirror 3. Optical combiner is just a half mirror combining real-scene rays and virtual-image rays to a single beam. The beam then goes through ocular and reflects on the double-face mirror, finally, jumps into user's eyes. Since the XGA LCD is used to realize virtual object blocking real ones, it should be placed at the position where is conjugate to the position of color LCD. Therefore, with the one magnification of telescope, user can see blended scene without parallax. An appearance of the HMD's system configuration and its outer frame are shown in Fig. 4 and Fig. 5, respectively.

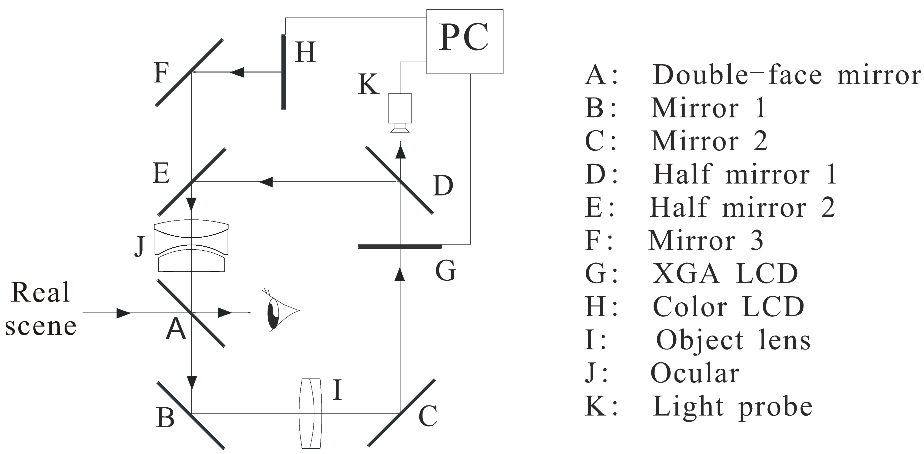

Fig. 3. The optics design of our OST-HMD

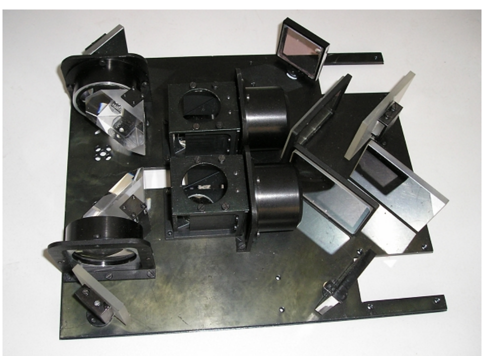

Fig. 4. The appearance of our HMD's System configuration

Fig. 5. The appearance of our HMD's outer frame

3 Intensity Matching

To achieve intensity matching between real and virtual environments is important for convincing AR applications as depicted by Oliver [5]. In our system, a camera with USB interface is employed as a light probe to detect illuminant condition of real scene.

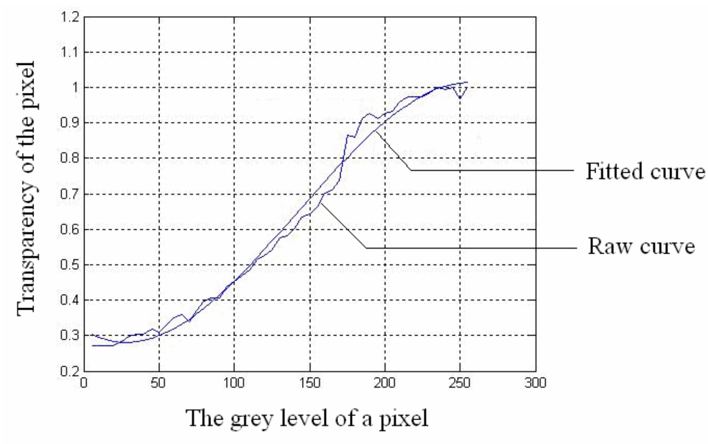

Fig. 6. The curves show how the transparency of a pixel varies as grey level of the pixel varies. Note that the smooth one is fitted curve while the other is raw curve.

Image captured by the probe is analyzed by PC and illuminant condition would then be estimated. The XGA LCD is the key device to adjust luminance of virtual object to the real scene. Since 8-bit gray level is included in every pixel of the LCD, there are 256 grey levels correspond to different luminance levels. In order to control the luminance of virtual object, we change grey levels of all the pixels synchronously. By turning up grey levels on the XGA LCD panel where real scene is brighter and by turning down them where virtual objects is brighter, consistent illumination between real and virtual objects can be achieved. We use a commercially available 0.9-inch LCD panel (SONY Japan, LCX029). Fig. 6 shows how the transparency of a pixel varies as grey level of the pixel varies. It is clear that the transparency of a pixel is nearly in proportion to its grey level. Actually, after curve fitting, we get an equation of the curve as:

$$Y = -1.2397 \times 10^{-7} x^3 + 5.2789 \times 10^{-5} x^2 - 2.6676 \times 10^{-3} x + 0.31637 \qquad (1)$$

In account of good smoothness of the curve fitted in Fig. 6, equation (1) can be used to judge what the value of LCD's transparency should be changed to in order to identify the corresponding grey level.

4 Mutual Occlusion

In an AR system, mutual occlusion of real and virtual environments enhances the user's feeling that virtual objects truly exist in the real world. Fig. 7(a) illustrates a case where a virtual bee would be overlaid on a real scene with a conventional HMD. We can observe that the bee is semi-transparent so that the blended scene is not reality. However, if mutual occlusion is used in system, a more vivid scene will be got as shown in Fig. 7(b)

(a) A scene without mutual occlusion. **(b)** A scene with mutual occlusion.

Fig. 7. Different synthetical scenes between mutual occlusion is used and not

Our system realizes the mutual occlusion correctly. Details of our method are as following: Real scene's images are synchronously captured by the two cameras attached on HMD. Then pose estimation [8] and depth judgment [9] are executed. Since every coordinate of virtual object is known in computer generated image, after pose estimation, we can superimpose the image upon the real scene correctly. Using the information from depth judgment, the virtual object can be judged whether it is in front of the superimposed real objects.

With our optical system, a viewer can simultaneously observe both outside scene and virtual objects on the LCD panel in focus. We can change brightness of the color LCD by turning up/down the light level of it. However, mutual occlusion cannot be realized just by the change since its range is too low. By turning down grey levels of pixels on the XGA LCD panel where virtual objects should appear, the transparence of corresponding pixels become lower. Thus virtual object blocking real ones can truly be presented optically. To realize real object blocking virtual ones, we use a pixels filter to mask virtual objects' pixels should be blocked in the color LCD. This work is done by PC rather than XGA LCD. In other words, we realize mutual occlusion in two different ways. One is controlling transparence of XGA LCD's pixels, and the other is rendering virtual object selectively. Fig. 8 and Fig. 9 show the two patterns of overlaid images. A virtual yellow cube is covered with a real toy in Fig. 8(b) while the rendered cube is shown in Fig. 8(a). In another experiment, seeing through the display of our HMD, we saw a virtual black triangle blocked a real tapeline (Fig. 9). These mutual occlusions improve the reality of synthetic scene.

(a) A rendered virtual cube. **(b)** The virtual cube is blocked by a toy.

Fig. 8. A pattern of overlaid that a real toy blocks a virtual cube

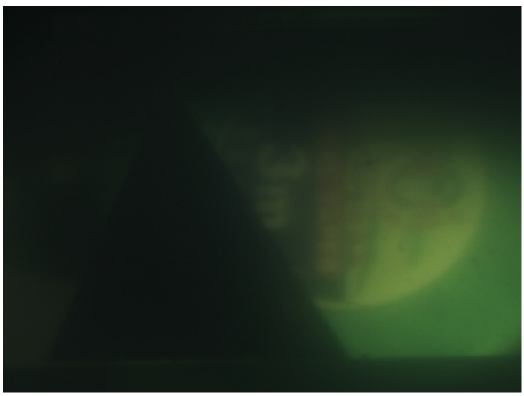

Fig. 9. A pattern of overlaid that a virtual triangle blocks a real tapeline

5 Conclusion

To attack the main disadvantages of typical OST-HMD, we designed a novel OST-HDM. Experimental results show that our system has the capabilities not only mutual occlusion but also illuminant matching without parallax. And these capabilities make a good effort to enhance the user's feeling that virtual objects truly exist in the real world.

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