Monolithic Low Cost plastic light guide for Full colour See-Through Personal Video Glasses

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Abstract:
Low cost see-through personal video glasses technology for consumer market was developed. Monolithic transparent plastic light guide with an array of small surface mirrors enables a bright image with a field of view of 27 degrees in an esthetic form factor.

1. Introduction:

See-through video glasses using Diffraction Optics have existed for some time. These technique use either a Holographic Optical Element [1] or deep Diffraction Grating [2]. Both techniques suffer from limited Field Of View (FOV) and from sensitivity to a color shift in the projected images that results from diffraction effect. Moreover, the cost of such systems is prohibitive for a consumer product application. Another technique uses semi-reflective polarized reflectors embedded into a glass light guide plate [3] with the disadvantage of heavy, breakable, and high cost components.
Finally other see-through techniques use semi-reflective curved mirrors placed in front of the eye with an off-axis optical system [4]. This technique suffer from a high amount of distortion. Moreover the optical architecture doesn't allow an esthetic form factor to appeal to consumers.
The technique we will describe hereafter (called Clear-Vu) has the advantage of using low cost reflective molded plastic components. It provides a see-through feature without the disadvantage of any color issue since it uses reflected light and simple mirrors.

2. Description of Clear-Vu technique:

Figure 1 below describes the basic principle. An optical collimator magnifies the image generated by a micro display. Consequently, any type of micro display could be used in this system (LCD, LCOS, OLED) with a slight adaptation of the collimator. The collimated beam is coupled into a monolithic light guide. The light propagates inside the light guide by Total Internal Reflection (TIR). The light guide has a small mirror array on its surface that extracts the image rays toward the pupil of the eye located in front of the light guide at a distance of about 15mm.

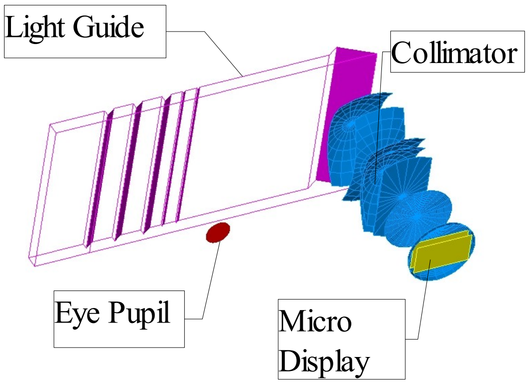

Figure 1: Principle of Clear-Vu see-through method.

The arrangement of these mirrors allows the image rays to be extracted and thus form a unique and bright image in the eye. Each mirror is separated by flat areas that allows the outdoor scene to be transmitted and seen by the eye. The mirror array is located close to the eye and is out of focus and thus will not be seen by the eye therefore allowing the see-through effect over the total field of view.
The key in this technique is the shape of the light guide. The light guide could then be produced by common low cost injection moulding techniques for plastic optics. The optical collimator is also made by a set of 3 plastic lenses that are also produced by injection moulded plastic. This architecture offers the major advantage of cost and weight reduction needed to address the consumer market.

3. Light guide functionality:

Figure 2 below shows the light beam path leaving the micro display, crossing the collimator, coupled and guided inside the light guide and finally extracted by the mirror array toward the eye pupil.

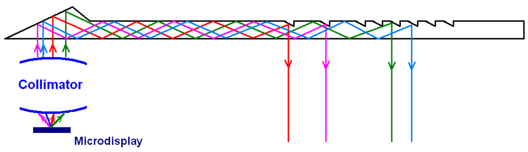

Figure 2: Light beam path inside the light guide.

The beam is injected into the guide after reflection on on the large wedge shaped mirror surface. The beam is then guided by Total Internal Reflection since the average beam angle of incidence is bigger than the critical angle of the light guide substrate. When the beam reaches the mirror array, it is reflected again by the array of small mirrors toward the eye.
The dimensions and arrangement of these mirrors are calculated to allow all the fields of the image to be extracted in a uniform fashion. The dimensions are also critical to maintain the system resolution. However, very small mirrors increases the diffraction effect and reduces image quality so a compromise needs to be found. The system shown in Figure 2 is using mirrors of ~750µm wide.
See-through ratio is the ratio between metallized and non metallized areas over the light guide surface. In the current system this ratio is about 50%. This parameter is a design value for light guide. It is possible to adjust this parameter to have a higher or lower see-through ratio.

4. Extended Eye Box:

All light beams extracted by the mirror array and crossing the plane of the eye pupil form an area where the image (or part of it) can be seen by the eye. Since the pupil dimensions range from ~3 to 4mm in average, the useful area that contains the whole image forms what we call the Eye Motion Box. It means, wherever the eye pupil is located inside this eye motion box, the viewer will see the whole image without any vignetting.
The Clear-Vu architecture has an eye box of H:9mm x V:4mm. This extended box has two major advantages: The first is to have a fully visible image when the eye moves inside the projected image itself. The second is to allow different viewers with different IPD (Inter Pupil Distance) to use the video glasses comfortably without any vignetting of the image. It is then possible to have video glasses with an IPD centred at 63.5mm for example and allow viewers having an IDP between 60 to 67mm to use the same glasses. These two advantages are important for visual comfort and for mechanical simplicity (there is no need for adjustment).

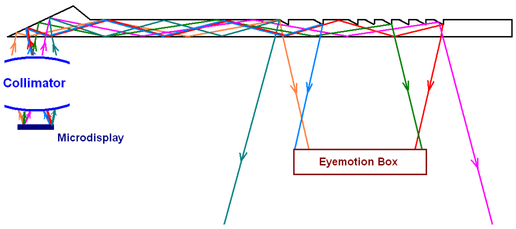

Figure 3: Extended Eye motion box for better visual comfort.

5. Optical performance:

The Clear-Vu concept offer a FOV of 27 degrees. The FOV is related to the number of mirrors and their arrangement. It is also related to the collimator focal length and Micro display dimensions. Higher FOV is possible through some trade-offs regarding overall system dimensions.
It is important to note that the architecture does not show any colour shift inside the Field of View, since the beam is either reflected by Total Internal Reflection or reflected by a metallic surface that does not introduces any spectral variation in reflectivity as a function of the incidence angle.
Image Brightness is related to Micro display Brightness. In the Clear-Vu concept as for the others mentioned in the references [1], [2] and [3] above, the relation between MD Brightness and perceived Brightness is related to the eye box design and light guide design. In this case the perceived brightness is less than MD brightness and is also a trade off with the box dimension. The larger the eye box the smaller the brightness and vice versa. In the case of the current Clear-Vu architecture, the ratio between Perceived Brightness and MD Brightness is about 30 to 50%.
Brightness Uniformity is related to the arrangement of the mirrors and their relative dimensions. It is also related to the Native Brightness uniformity or the Micro display it self. The current architecture has a Brightness uniformity of greater than 50% over the entire image.
The resolution capability was demonstrated using high resolution micro display panels

(WVGA & SVGA) with a pixel size as small as 10µm. Figure 4 shows MTF rendering for an 0,59 inch SVGA OLED panel with a pixel of 15µm.

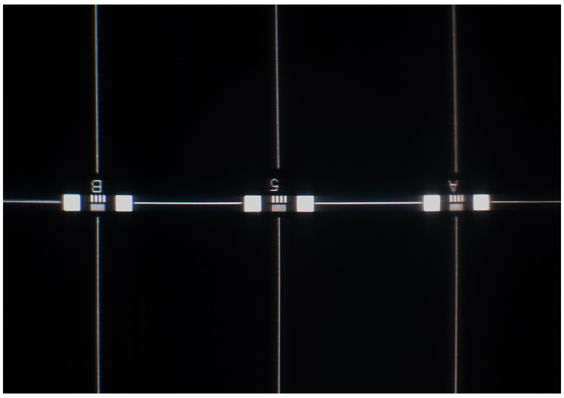

Figure 4: Clear-Vu image rendering with an MTF pattern.

6. Experimental results:

Figure 5 shows an image of the video glasses prototype which was built. Regarding the general aspect of these video glasses, solar filters were used to improve the contrast of the image in a high brightness environment. Currently, the volume of the collimator suffers from the fact that today's micro display packaging is not optimized for this particular application.

Figure 5: Photo of Clear Vu prototype

Table 1 below summarizes the performances of the prototype:

FOV	27 degrees
Micro Display size	0.44inch RGB LCD, (compatible with others)
Resolution	VGA: 640x480 pixels
Eye box	H:9mm x V:4mm
Brightness	150Cd/m²
Eye relief	15mm
IPD (range)	63,5mm (60 to 67mm)
Weight (optical parts)	12g (for each eye)
Distortion	<0.7%
MTF (@33lp/mm)	35%
See-through ratio	50%

Table 1: Summary of prototype performances.

7. Conclusions:

The concept of see-through video glasses using a monolithic plastic light guide has been demonstrated. The system exhibits 27 degrees FOV and good optical performance. The system has low weight and cost to address the consumer market.

References:

[1]: H. Mukawa. K. Akutsu, I. Matsumura, S. Nakano, T. Yoshida, M. Kuwahara, K. Aiki, M. Ogawa, "A Full Color Eyewear Display using Holographic Planar Waveguides' SID 08 Digest, pp. 89-92.

[2]: T. Levola, "Steroscopic Near to Eye Display using a Single Microdisplay" SID 07 Digest, pp. 1158-1159.

[3]: PCT 2006 013565 A1, Lumus patent.

[4]: Hoshi et all, "Off axis Optical system consisting of aspherical surfaces without rotational symmetry" In Proc. Of SPIE volume 2653.