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Design of a 360-degree holographic 3D video display using commonly available display panels and a paraboloid mirror

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ABSTRACT

Even barely acceptable quality holographic 3D video displays require hundreds of mega pixels with a pixel size in the order of a fraction of a micrometer, when conventional flat panel SLM arrangement is used. Smaller pixel sizes are essential to get larger diffraction angles. Common flat display panels, however, have pixel sizes in the order of tens of micrometers, and this results in diffraction angles in the order of one degree. Here in this design, an array of commonly available (similar to high-end mobile phone display panels) flat display panels, is used. Each flat panel, as an element of the array, directs its outgoing low-diffraction angle light beam to corresponding small portion of a large size paraboloid mirror; the mirror then reflects the slowly-expanding, information carrying beam to direct it at a certain exit angle; this beam constitutes a portion of the final real ghost-like 3D holographic image. The collection of those components from all such flat display panels cover the entire 360-degrees and thus constitute the final real 3D table-top holographic display with a 360-degrees viewing angle. The size of the resultant display is smaller compared to the physical size of the paraboloid mirror, or the overall size of the display panel array; however, an acceptable size table top display can be easily constructed for living-room viewing. A matching camera can also be designed by reversing the optical paths and by replacing the flat display panels by flat wavefront capture devices.

Keywords: Holographic 3DTV, Holographic video, Holographic displays

1. INTRODUCTION

An ideal true three-dimensional display targets an exact duplicate of the volume of light field captured at the site of the original scene. Any form of a technique that targets such an exact duplication of the volume filling light field is called a holographic technique.[1] Naturally, depending on the capabilities of the intended observers, those physical features of the original light that are definitely not detectable or usable by the observers, may be omitted while attempting the exact duplication. Current holographic displays usually modulate an incident uniform light over a surface to generate a time-varying boundary condition in the form of a fringe pattern; the fringe pattern diffracts the incident light to generate the outgoing desired light field.[2–5] The theory of scalar diffraction is well understood.[6] In practice, usually spatial light modulators (SLM) are used to generate the desired 3D field.[2–5, 7–13] SLMs are electronically controlled pixellated devices that either modulate only the amplitude or the phase of each pixel. It is possible to design devices based on SLMs to effectively achieve both amplitude and phase modulation.[14] SLMs are either transmissive or reflective. Commonly available SLMs have a planar geometry. A consumer quality 3D holographic video display with a planar geometry SLM requires a very large array of very small pixels.[5] A large overall display size (array) is needed to achieve acceptable 3D image size, whereas the small pixel size is needed to achieve larger diffraction angles, and therefore, to achieve larger viewing angles with a sufficient resolution. A simple calculation yields numbers like array sizes of 10^{10} pixels, where the pixel size is in the order of a micron even for a modest 3D image size of about maybe 10 cm in each dimension.

Here in this work, we present a 3D holographic video display design that overcomes the abovementioned difficulty by achieving large viewing angles by reflecting the diffracted light from a paraboloid mirror. The light is diffracted by an array of planar SLMs where each SLM has an array size and pixel size specifications comparable to the cellular phone displays in use today. Therefore, pixels are relatively significantly larger than

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a micron, and therefore, the diffraction angles generated by the planar SLMs are quite small. However, such small-angle diffracted field is then reflected by a paraboloid mirror segment, and based on the design geometry, the collection of such diffracted and then reflected beams collectively form a high-quality 360 degrees viewing angle 3D holographic image. Holographic displays with 360 degrees viewing angle are highly desirable; examples of different 360 degrees viewing angle holographic display designs can be found in the literature.[15]

2. HIGHLIGHTS OF THE DESIGN

The design is based on the geometry and the principles of a commonly available toy made up of a paraboloid mirror pair that is used to relay the real image of a physical object from around the focal point of one such mirror to the focal point of the other one (Figure 1).[16] The key design goal is the capture, and then the replay, of the wavefront over a surface somewhere between the two mirrors. Therefore, the two mirrors in the pair are physically split into two stand-alone mirrors. Conceptually, the one at the top in Fig 1 becomes the holographic camera, and the one at the bottom becomes the holographic display. The surface indicated by the dashed line in Fig 1 is covered with a tile of wavefront capturing devices at the camera side; we will not discuss the camera side here in this paper. The corresponding surface at the display side is tiled by spatial light modulators to regenerate the captured and then stored/transmitted wavefront.

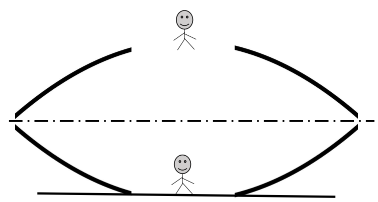

Figure 1. The basics of the famous two-paraboloid mirror toy. The real image around the focal point of the bottom mirror is obtained and relayed from the object around the focal point of the upper mirror. The dashed line shows a sample surface, which is planar in this case, where the wavefront may be captured.

As both reflective and transmissive spatial light modulators are used for holographic displays to regenerate the wavefront, there are also two alternative designs. In either case, a circularly symmetric light obtained by spreading the incoming collimated light beam by a cone mirror illuminates the spatial light modulators tiled over the surface via reflection from a set of circularly shaped mirror belts placed around the paraboloid mirror. (Fig 2).[3,17] A transmissive SLM case is shown in Fig. 2. The essential feature of the design is the utilization of SLMs with rather low spatial bandwidth, and therfore, the maximum diffraction angle, α, of the diffracted light at the exit side of the SLMs is rather small. Therefore, typical LCD displays, commonly used for cellular phones can be utilized as SLMs. An array of such SLMs are tiled to cover the entire planar surface on top of the paraboloid mirror, except the central circular opening needed to pass the light which would then form the 3D real image. Footprint of the diffracted light from a small local patch on the SLM on the paraboloid mirror surface is therefore rather small. Therefore, the corresponding beam segment from that area of the paraboloid mirror is also rather narrow. However, since the SLM tile covers a large planar surface on top of the paraboloid mirror, each such small beam component from different segments of the SLMs is reflected at a different angle by the corresponding local paraboloid mirror patch to yield a true 3D image visible from a wide viewing angle; the viewing angle is full 360 degrees horizontally (azimuth) based on the orientation shown in Fig. 2. Also a wide vertical viewing angle, that is only limited by the aperture geometry, is achieved. The vertical viewing angle may be improved by modifying the planar surface that the SLM array is mounted. Instead of a planar surface, a conical surface yields a tilted geometry, and therefore, enlarges the effective opening at the exit, as shown in Fig. 3. If a reflective SLM is preferred, a circularly symmetric beam splitter is needed to direct the incident light to the SLMs, as shown in Fig. 4. The beam splitter is also a circular belt; in case of the tilted geometry, the beam-splitter belt also has conical surfaces to match the tilt.

The general view of the overall design is depicted in Fig. 5. The outer case encloses all the input illumination optics including the cone mirror, circular mirror belts, beam splitter belt if any, and the paraboloid mirror. The

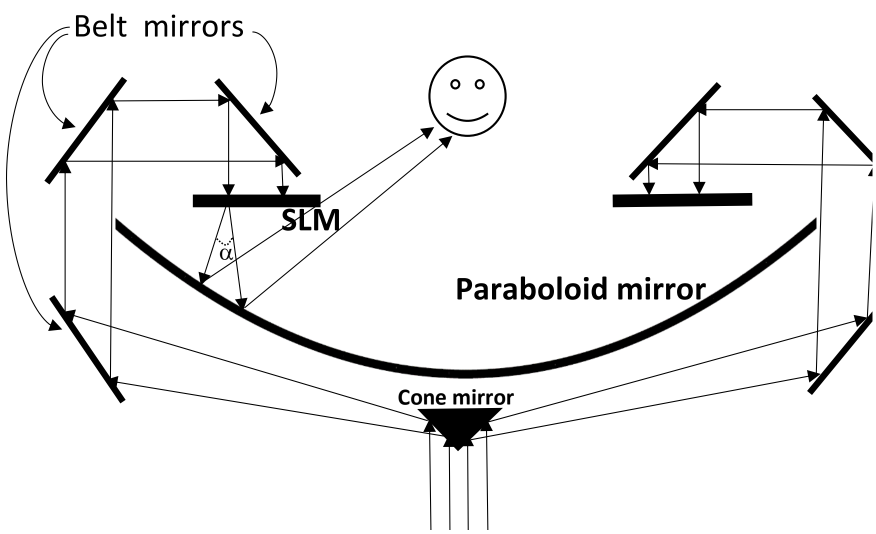

Figure 2. The central cross-section of the circularly symmetric basic design. The collimated beam hits a cone mirror and spreads in a circularly symmetric fashion (360 degrees) towards the circular belts of tilted mirrors to eventually illuminate the tiles of SLMs (transmissive SLM case is shown).[16, 17]

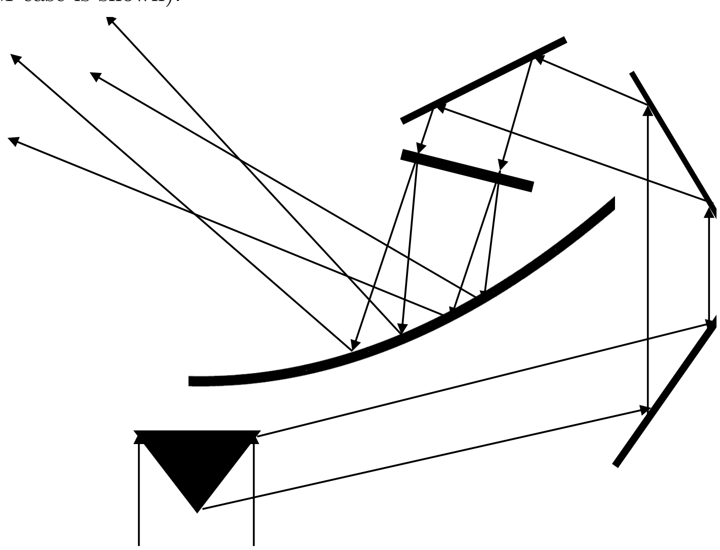

Figure 3. A tilted geometry improves the vertical viewing angle. (Only one side of the cross-section of the circularly symmetric design is shown.)[16]

array of SLMs are also in the case. Naturally, the captured (by the camera) or computationally generated video fringe patterns should be written on the SLMs at video rates; conventional high-end computers are needed to drive such SLMs. These supporting computer units, and the needed interfaces are not shown in the figures.

3. CONCLUSION

A holographic true 3D video display design based on paraboloid mirror is presented. Both transmissive or reflective SLM array versions are shown. The main purpose of the design is to utilize rather larger pixel SLMs with consequently low diffraction angles while achieving a 360 degrees viewing angle with a good video quality.

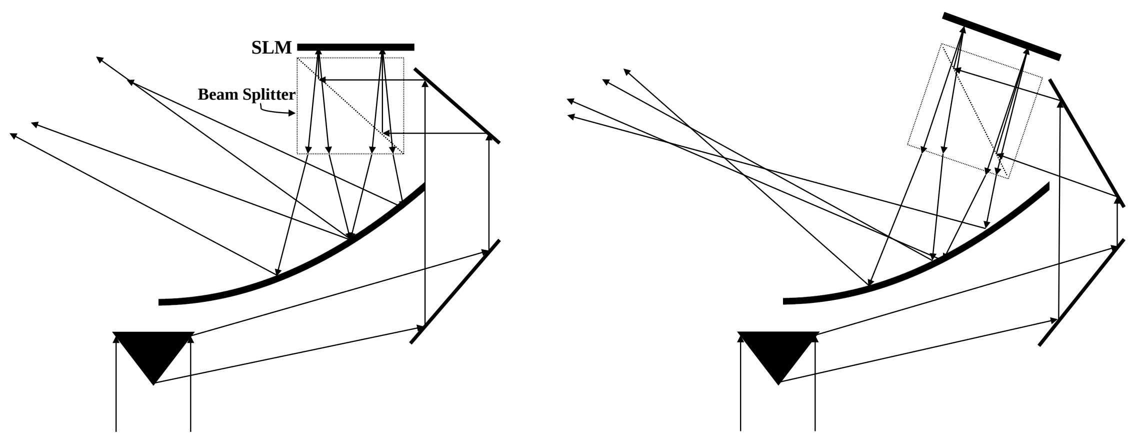

Figure 4. If a reflective SLM is used, a beam splitter provides the illumination. A planar SLM array geometry is shown on the left, whereas, a conical (tilted) version is on the right.[16]

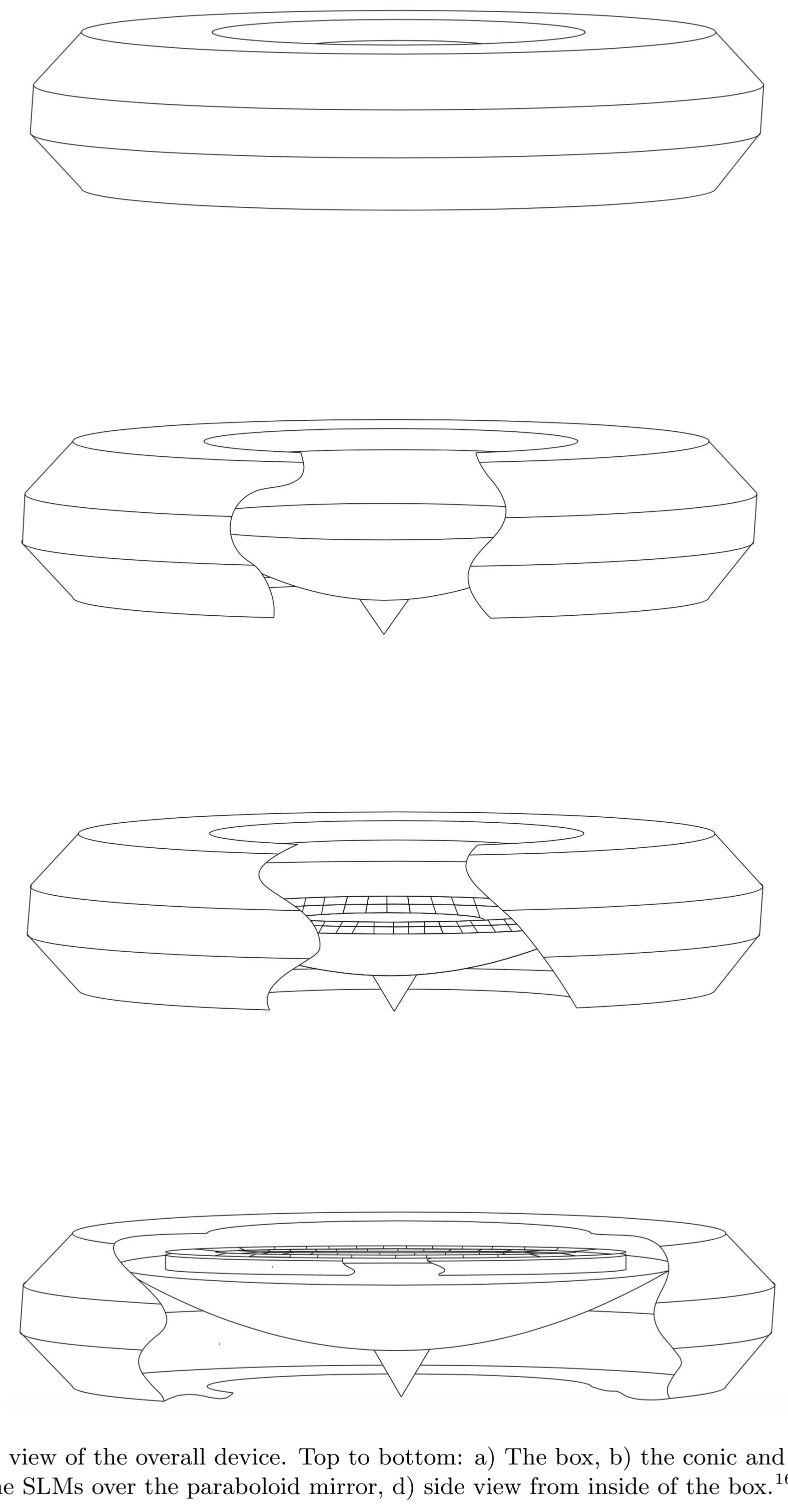

Figure 5. The schematic view of the overall device. Top to bottom: a) The box, b) the conic and the paraboloid mirrors inside, c) the tiling of the SLMs over the paraboloid mirror, d) side view from inside of the box.[16]

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