CATEGORY: AUGMENTED REALITY & VIRTUAL REALITY - AR01

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# High Efficiency Near-Eye Light Field Display

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## 1. Abstract

We present a design for a near-eye light field display that supports accommodation and retinal blur while preserving high spatial resolution and operating with the same bandwidth requirements of a conventional display. In a simple hardware design, a light source array is used to reflect light in multiple directions off a high speed binary display, creating a light field over the eye. The display bandwidth conventionally used to create color gradations is instead used to create a high angular resolution *binary* light field with the expectation that the color gradations will be partially recovered when the light field is collected by the eye and focused back to a point on the retina. The proposed design is analyzed with preliminary simulations and prototype hardware.

## 2. Motivation

Existing near eye light field displays have shown the benefits of providing focal depth cues, namely enhanced realism and elimination of the visual discomfort caused by the accommodation-convergence conflict. However, synthesizing such high light field typically comes at a high cost which has so far limited practicality: a significant loss in spatial resolution [1] or a corresponding increase in display bandwidth [2], often by a factor of 25X or more. In this work we explore an approach for preserving high spatial resolution while using conventional levels of display bandwidth on high speed binary color displays.

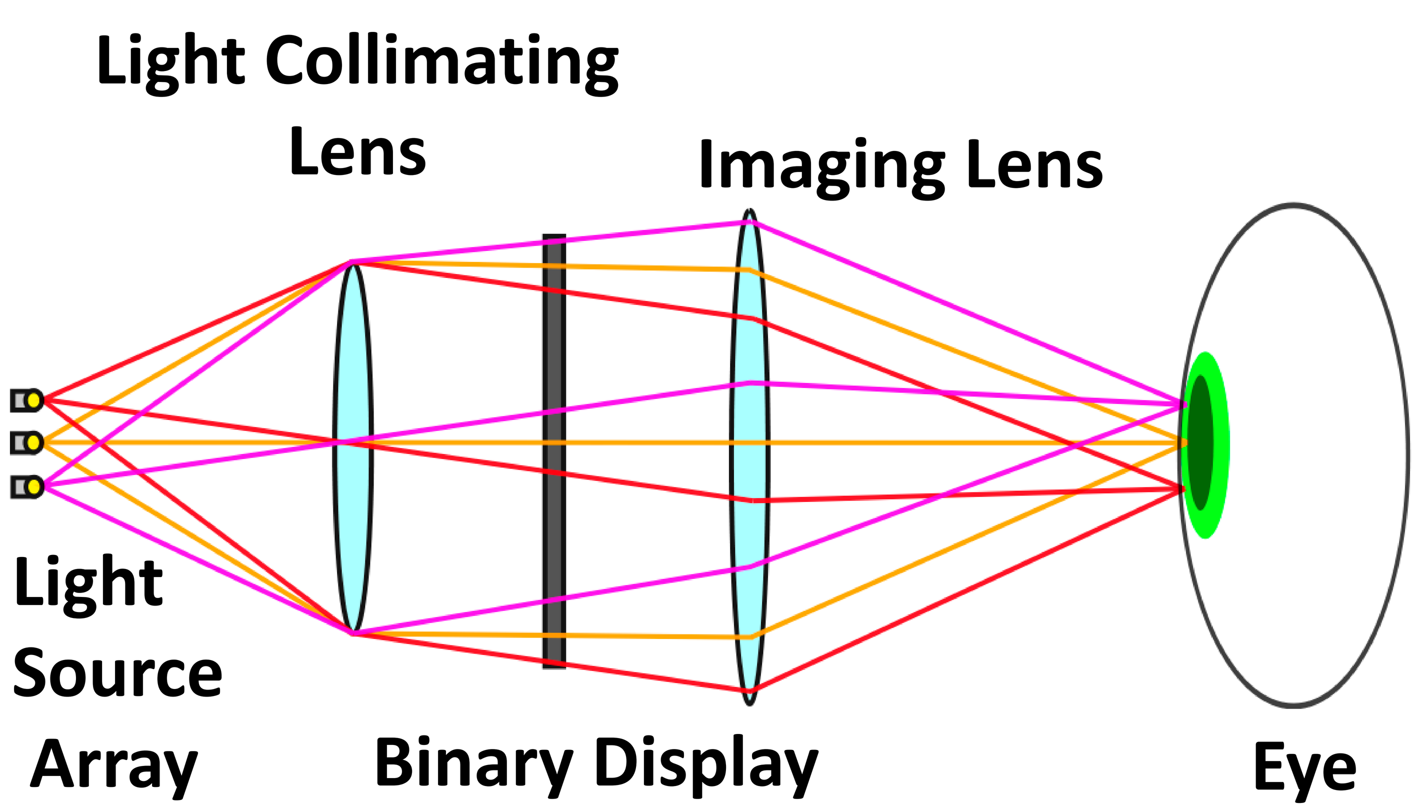


*Figure 1*: Conceptual optical design. Elements from a light source array are illuminated in sequence, collimated, and modulated by a binary display. This display is then imaged through a lens, creating a light field over a small area on the pupil. (Note that the prototype uses a reflective display and the same lens is used for both light collimation and imaging the display.)

*Figure 3*: Display simulations. Left: simulated depth of field of binary light field display using 24 red, green, or blue rays per pixel and simple dithering algorithm. Center: Binary light field display with a σ = 1 pixel Gaussian low pass filter. Right: Reference image using 24 full color (24-bit RGB) images.

## 3. Method & Results

In the proposed design, a light array steers light onto a binary reflective display at multiple angles, which is then focused to different points on the eye, creating a miniature light field on the eye (see Figure 1). A Digital Light Processing (DLP) module is used for the display and LEDs are used for the light source array, allowing dynamic solid state light steering. In this configuration, each of the rays steered off the display is binary color, allowing the display to increase angular resolution at the expense of light resolution. However, for imagery in focus, all of these rays will be focused to a point on the retina and thus their intensity values will be summed, creating intermediate gray levels (see Figure 2). The binary color values can be generated with simple dithering to achieve acceptable results (see Figure 3), but it is expected that better performance can be achieved with an optimization. Optimization can also be improved by varying LED intensity levels and illuminating multiple LEDs at once, compressing spatially and angularly. A prototype display is pictured in Figure 4 and results on the display are shown in Figure 5. Note that both the simulated and prototype results use the same amount of display bandwidth as a conventional 2D display, although quality can be improved if more bandwidth is available. Further work is needed to create a human viewable display with optimal image quality, and eye tracking will be needed to create a wide field of view display while remaining bandwidth-efficient.

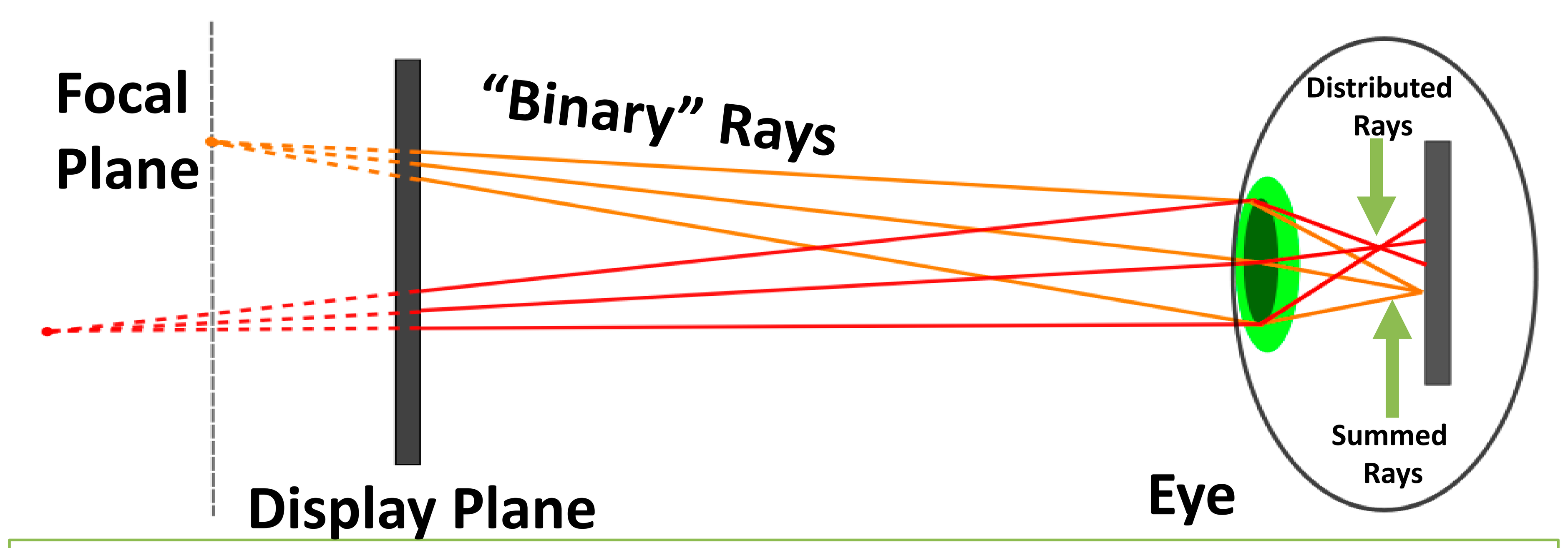


*Figure 2*: Display concept. Points at varying focal depths are reproduced on a high speed binary color depth display. For image points on the eye's focal plane, the binary color rays are summed when focused on the retina, improving color depth. For image points out of focus, the binary rays are distributed over a larger spot on the retina, creating a noisy approximation of focal blur.

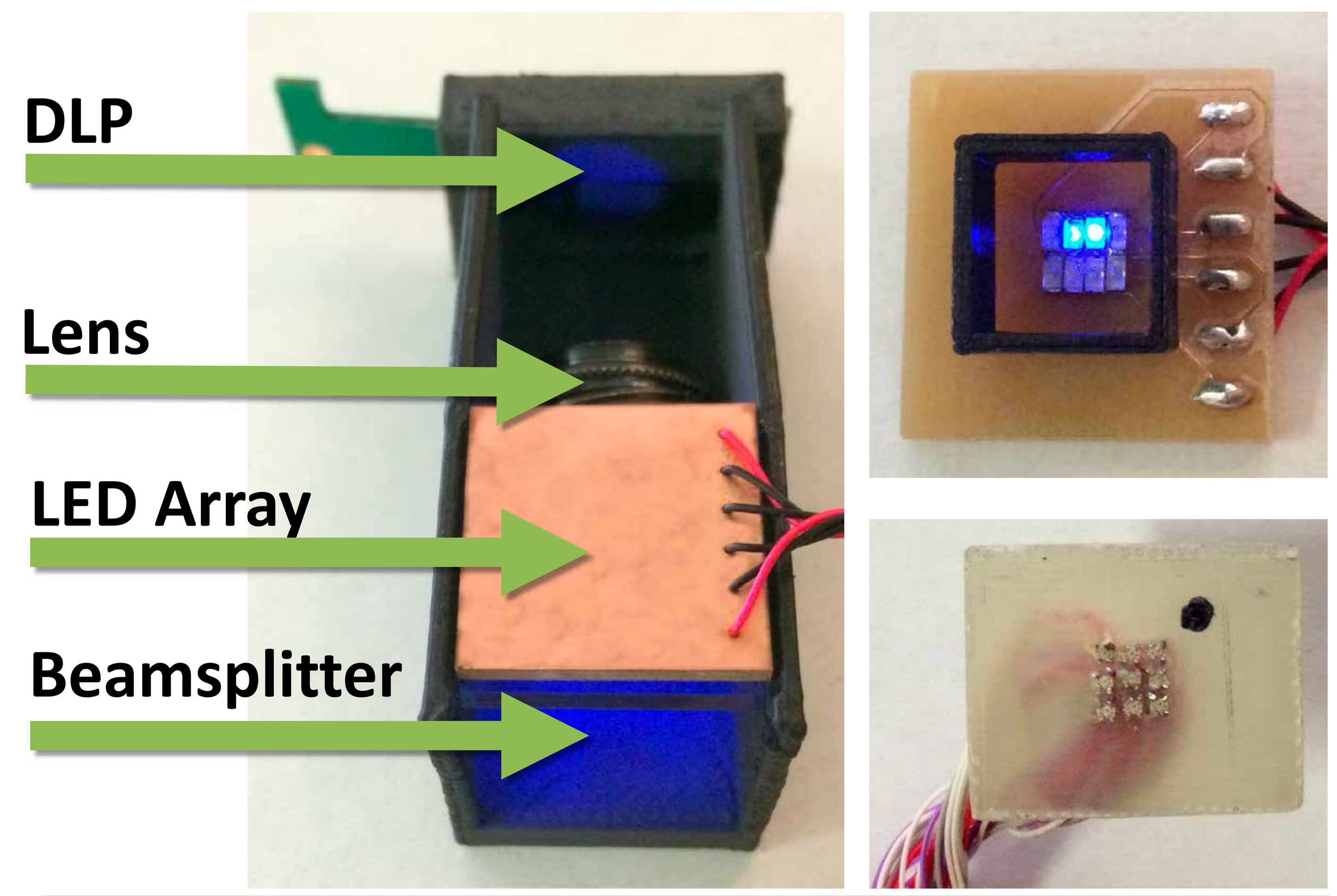


*Figure 4*: Prototype display. Left: Labeled unit. Top Right: 2x4 monochome LED array. Bottom Right: 3x8 tiled-RGB LED array.

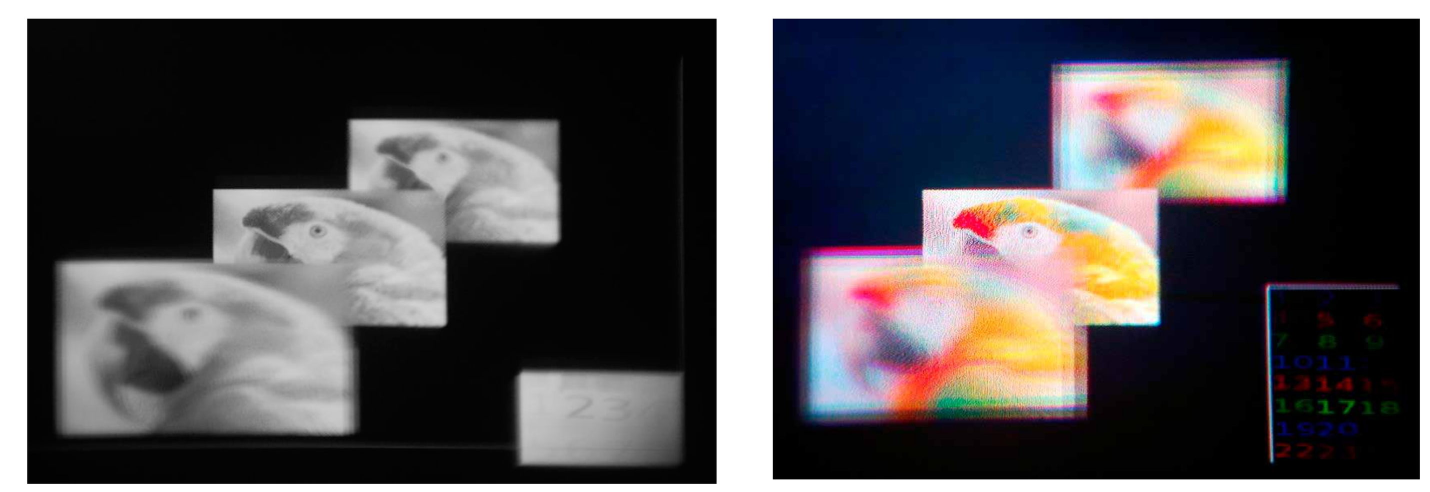

*Figure 5*: Photographs of prototype display showing depth of field. The three birds are displayed in a light field with increasing focal depth from left to right in each image. Left: Monochrome display with 8 rays and per pixel and 3 color bits per ray. Right. Color display using 24 rays per pixel and 1 color bit per ray. The light field in the monochrome case spanned approximately 4 mm.

## 4. References

[1] Douglas Lanman and David Luebke. 2013. Near-eye light field displays. *ACM Trans. Graph.* 32, 6, Article 220 (November 2013)

[2] Sheng Liu, Hong Hua, and Dewen Cheng. 2010. A Novel Prototype for an Optical See-Through Head-Mounted Display with Addressable Focus Cues. *IEEE Transactions on Visualization and Computer Graphics* 16, 3 (May 2010), 381-393.