AnyLight: An Integral Illumination Device

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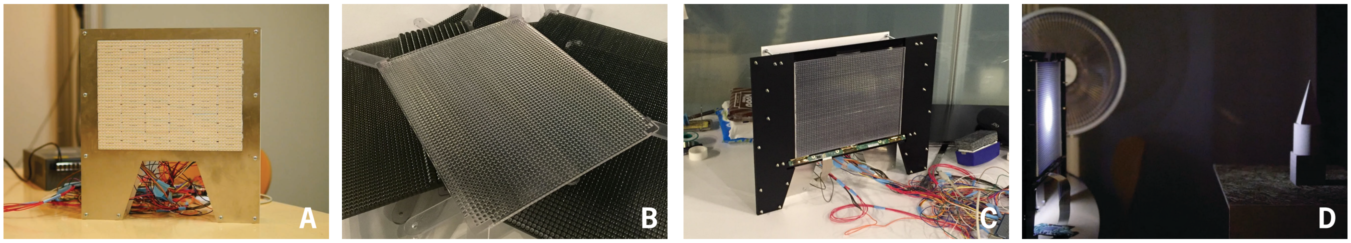

Figure 1: *A) High-power backlight. B) 3D printed lenticular sheets. C) Assembled prototype. D) AnyLight in use.*

Abstract

We introduce AnyLight, a novel programmable lighting device that can mimic the illumination effects of a broad range of light sources —both real and imagined—using the principle of integral imaging. The flat, panel-shaped device functions in essence as a type of light field display, relying on custom, 3D printed optics to precisely control light rays emanating from each point on its surface, simulating the existence of arbitrary light sources concealed within the device, e.g., spotlight, candle, skylight, etc. A room illuminated with AnyLight would allow occupants to manipulate ambient lighting with a degree of freedom unreachable using existing programmable lighting setups, where typically color is the only adjustable parameter.

Keywords: Integral illumination; integral imaging; computational light fields; programmable lighting.

Concepts: •**Hardware** → **Emerging technologies;** *Emerging optical and photonic technologies;*

1 Introduction

Integral imaging [LIPPMAN 1908], a technique invented more than a century ago, is now being used as one of the most popular methods to implement stereoscopic or multiscopic 3D displays. In principle, integral imaging is capable of realizing a *light field display*—i.e., a device that can produce arbitrary 4D plenoptic light fields. (In practice, the technique entails a number of tradeoffs and limitations that restrict the range of light fields it can generate successfully.) A *true* light field display will act as a highly lifelike 3D display, supporting stereoscopic depth and motion parallax with no need for specialized glasses; virtual objects shown on the display will realistically seem to exist within the device, beneath its planar surface.

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We introduce AnyLight, a device that makes use of this principle of integral imaging to realize a more versatile form of "programmable lighting"—a name often used in industry to refer to color-adjustable LED bulbs, e.g., Philips Hue. Although relying on a timeworn principle, there are two recent technical advances that serve as enablers for AnyLight. The first is the steady improvement in LED technology; light output has increased significantly, while power consumption and heat production have both been diminished. The second is the introduction of 3D printable optics, that allows us to easily fabricate custom optical elements, including those with rather complex designs that would have made them cost-prohibitive with traditional manufacturing methods. Due to these technical advances, it is now possible to build AnyLight at a relatively low cost, and with a compact, flat form factor.

2 Related Work

Integral imaging, and its use for stereoscopic 3D displays have been well documented [XIAO 2013]. While the technology itself is simple and its properties have already been studied extensively, we still see periodic advances; for example, some recent work has explored the use of 3D printed optics for integral imaging [TOMPKIN 2013]. As mentioned earlier, real-world implementations of integral imaging involves numerous tradeoffs, e.g., spatial versus angular resolution. In a typical stereoscopic display implementation, angular resolution is sacrificed to achieve acceptable spatial resolution.

The concept of using digital technology to realize "programmable" lighting is an old one, and a number of researchers have investigated the use of digital projectors as next-generation illumination devices [UNDERKOFFLER 1999]. However, projectors by themselves can only offer limited programmability (if not used in combination with integral imaging [MATUSIK 2004]), as they do not permit modulation of any photic parameter besides the color of each pixel.

AnyLight is not the world's first system to use integral imaging for programmable lighting; similar efforts have been made in the past, albeit focusing on smaller scales than architectural or ambient illumination [COSSAIRT 2008; LEVOY 2006]. Our hardware setup is largely built on such prior efforts, with some modernizations necessitated by the difference in scale and application domain.

Conceptually, AnyLight owes to Sutherland's idea of the "ultimate" display [1965], and also to more recent work that explores the possibility of realizing architectural spaces "endowed with the plasticity and interactivity of digital bits" [TAKEUCHI 2014].

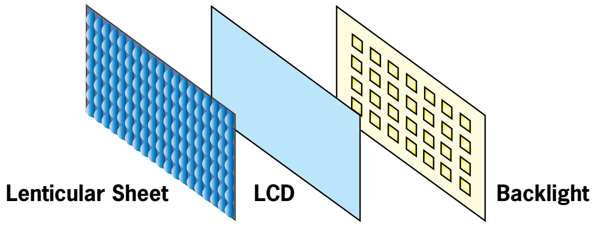

Figure 2: *Hardware configuration.*

3 AnyLight

Figure 2 depicts the hardware configuration of AnyLight. There are three main components: 1) LED-array backlight, 2) LCD panel, and 3) lenticular sheet. This setup is roughly identical to common integral imaging displays—the only major differences are the output of the backlight (Figure 1A; our custom backlight is designed to generate hundreds of times more luminous flux than a typical LCD panel of comparable size), and the design of the custom, printed lenticular sheet in which black, opaque "walls" surround each lenslet (Figure 1B). The walls minimize crosstalk between light coming out of adjacent LCD pixels, which keeps unintended rays from being emitted at angles greater than each lenslet's angle of view (we refer to these unintended light rays as "ghosts"). Note that ghosts are not an issue for stereoscopic displays or small-scale integral illumination, which are only concerned with controlling light that enters a specific area (*area of concern*), and any light that does not enter this area can be safely ignored. This is not the case with ambient lighting, where *all* light coming out of the device must be precisely controlled. As the high-power backlight generates significant heat, we use both active and passive heat management technologies to prevent overheating. (Future designs may abandon the use of LCDs to decrease heat production and energy use).

Since the lenticular sheets are 3D printed, their designs can be optimized to suit specific usages and/or installment locations. The lenslets' angle of view can be adjusted according to room dimensions, for example, and some applications may benefit by designing sheets with non-uniform (and perhaps also non-radially symmetrical) lenslets. For example, if we consider installing AnyLight on the ceiling of a narrow hallway, it might make sense to design the sheet to have a wider angle of view in one direction (parallel to the hallway) compared to the other.

Figure 3 depicts several lighting effects generated by our AnyLight prototype. The screen is approximately 25cm wide and 19cm tall—the setup can be scaled up either by making each of the components bigger, or by tiling multiple small AnyLights.

4 Conclusion

We have introduced AnyLight, a programmable lighting device that makes use of integral imaging. Future work includes improving the energy efficiency of the hardware by replacing the LCD with an alternative light source (e.g., LED matrix display), exploring different form factors and lenticular designs, and developing intuitive control mechanisms to interact with the device.

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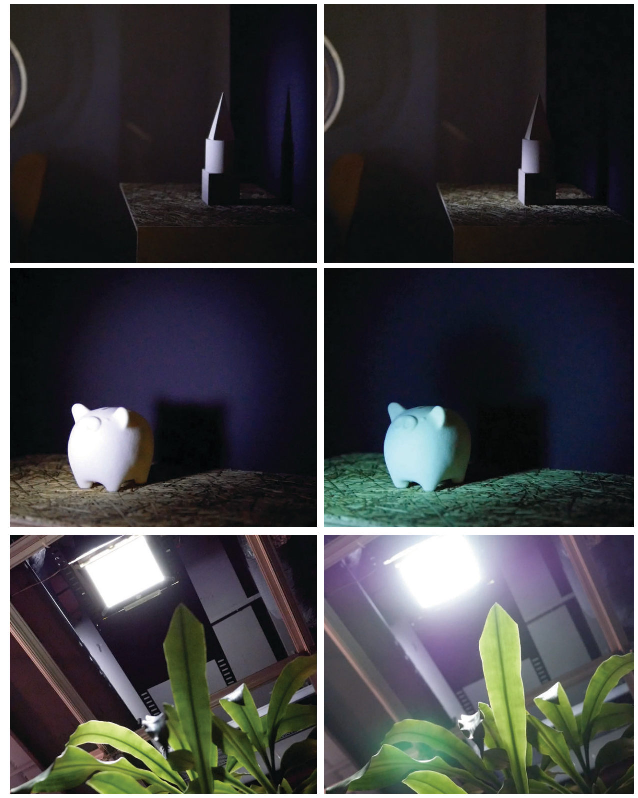

Figure 3: *Example lighting effects produced by our prototype.*

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