The Improvement of Efficiency and Uniformity in Non-image LED Illumination for Field-Sequential-Color Pico-projector

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Abstract — In this paper, the efficiency and uniformity improvement of non-image LED illumination system with collimator, microlens array and condenser are proposed for pico-projector. The LED light is collimated to 18 degree with efficiency 99.36% by collimator. For image uniformity and flux efficiency, the doule-side microlens array and two condensers are adopted to form a homogenizer. With this homogenizer, the uniformity of panel can be improved to 84.75% ANSI and LEDs outputs utilization of 15.31% can be obtained within the non-image system volumes of 34mm ×12mm × 12mm.

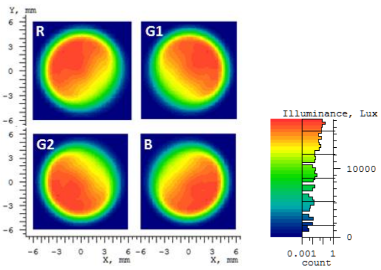
Introduction

As information technology grows rapidly, portable digital devices such as cell phones, game players, cameras, etc. are generally carried with users every day. However, information share and human computer interface (HCI) on such device is limited by non-expandable dimensions of displays. Pico-projection technology presents a potential method to extend display size for portable digital devices. Also provides a new platform on HCI applications. Nevertheless, this small-size optical device faces many difficulties when it is practiced. Strict volume limitation in optical elements seriously degrades optical utility and imaging quality. Of commercial pocket projector, DLP, LCD, and LCoS panels are widely used for light valves; LEDs and LDs, for light sources [1, 2]. However, optical engine used in such commercial device is still too large to be embedded in cell phone, game players and so on. In consideration of safety problem caused by Laser pico-projector, we select color sequential type LCoS panel and multi-color LED array for our projection design focus. In this paper, we demonstrate a practical design of illumination system within a compact volume of 34mm ×12mm × 12mm. Also, numerical analysis of optical uniformity and optical utility are presented.

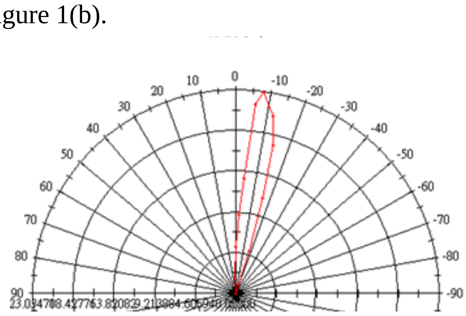
Non-image LED illumination system in pico-projector

The LED-based non-image illumination system contains an RGB LED array, collimating lens, a homogenizer, a condenser, a polarization beam splitter (PBS), and a light valve. In this paper, optical uniformity and flux utility are evaluated on a 0.22” VGA CS LCoS panel. The LEDs we use in this contribution are OSRAM OSTAR (LE ATB S2W) projection LEDs[3]. This is LED module with 4 dyes of 1 by 1 mm^2 with 0.1mm spacing. The effective radiation area of 2x2 mm^2 is approximately 1/3 of the panel size and the flux is lambertian distribution. Therefore, the second optics in the non-image LED illumination system is necessary for improvement of flux utility and uniformity.

For the collimation and optical utility in this system, the collimator with 2 lenses within a volume of 10x12x12 mm^3 is designed for LED light source. And it collimates the lambertian to scattering emission within a view angle of 18° with beam size 10 mm. Due to the arrangement of the four dyes, the collimator is unable to project RGB light on same region exactly. Figure 1(a) shows a circular projection pattern from each dye evaluated behind collimator. Such non-centrosymmetric effect in this distribution also causes the tilt of beam direction with 10° from the optical axis as shown in Figure 1(b).



(a)



(b)

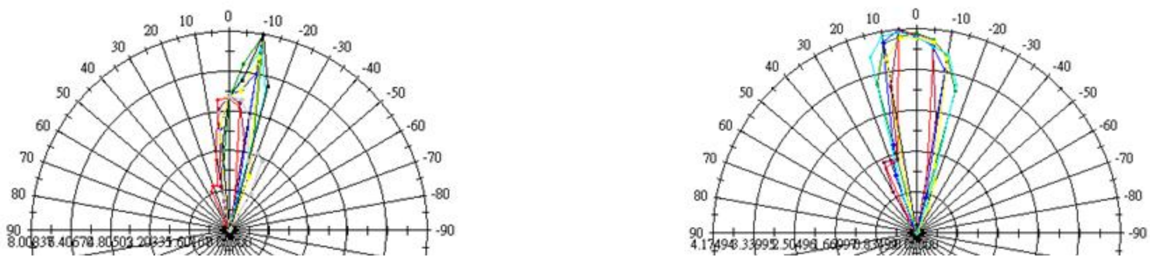
Figure 1. (a) Non-centrosymmetric projection pattern with 10-mm beam size from each dye evaluated behind

collimator. (b) Distribution of collimation light within 18 degree with 10° tilted from optical axis.

There are three issues, projection shape, uniformity, and centrosymmetry, should be further improved after collimator. Therefore, the microlens array in accompany with a condenser is utilized to be a homogenizer for the following reasons. It can promote the uniformity [4] and also adjust the shape and the size of projection distribution. To reduce the volume of homogenizer, we adopt a bi-convex microlens array [1] with a curving focal plane on the second surface instead of two lens arrays [5].

Because of the projection pattern is out of the active region of LCoS without any modulation. Such circular-shape projection and beam-direction tilt would seriously degrade the system optical utility. For modifying the projection shape, the dimension of a single bi-convex microlens is set proportional to the LCoS aspect ratio of 16:9. The rectangular-shape microlens is expected to modulate the circular projection pattern to be a rectangular one. To adjust the beam-direction tilt and achieve the optimum optical utility, the cross talk effect of microlens array and etendue loss should be eliminated. If the divergence of the incoming light is larger than the numerical aperature (NA) of microlens array, the crosstalk between neighbored lens array channels occurs, which lowers the useful transmission into the homogeneous illuminated area in the image plane and also prohibits etendue conservation [5]. For the best modification performance, the effective angle ($\theta_{microlens}$) presented by the NA of microlens is required to be larger than the emission distribution angle of collimator ($\theta_{collimator}$). Figure 2 shows two modifications by using a microlens array with $\theta_{microlens}$ of 10° and 18°, respectively.

The condenser behind homogenizer collects light within the active region of LCoS panel. For elimination of etendue loss, the microlens NA is also required to be smaller than the NA of condenser. We can obtain an optimum relation among the three angular parameters, which is presented by an inequality, $\theta_{collimator} < \theta_{microlens} < \theta_{condenser}$, where the $\theta_{condenser}$ is the effective angle presented by the NA of condenser. In pico-projection system, the maximum $\theta_{condenser}$ is limited by F number of the image system and the minimum $\theta_{collimator}$ is limited by the LED chip size. Figure 3 shows our non-imaging system scheme. For the chip size and the panel size are both already fixed in our system, we have to optimize the $\theta_{microlens}$ to 15.6° with consideration of uniformity and etendue loss. In design of the condenser, we utilize two lenses to reduce total track of illumination system [1]. As Figure 4 shows, light emitting from the homogenizer can be collected almost into the active region (the area inside the dash line).



(a) (b)

Figure 2. Angular distribution modified by two sets of microlens array (a) with $\theta_{microlens}$ of 10°. (b) with $\theta_{microlens}$ of 18°.

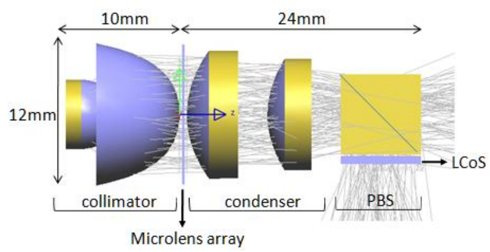


Figure 3. Non- imaging system layout. The PBS size is 5mm×6.9mm×6.9mm, and S wave reflectance and P wave transmittance of PBS is up to 85% within 15°.

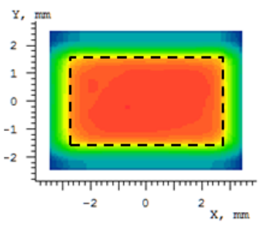


Figure 4. Projection pattern on LCoS panel. The area inside dash line is active region. Outer of dash line is defined as overfill.

For analyzing the uniformity of LCoS, we define the uniformity according to ANSI (NAPM IT 7.228-1997) for the following discussion. The performance on LCoS of non-image system is evaluated with pattern uniformity, relative position (as shown in Figure 5(a)), and the flux efficiency. Therefore, the fabrication tolerance of microlens array is analyzed as shown in Figure 5(b). In this curves, the uniformity and y-direction shift of pattern on LCoS vary with the $\theta_{microlens}$ significantly. Within the $\theta_{microlens}$ region of 14° to 17°, the uniformity on LCoS can maintain up to 88% and the pattern shift is under 0.24 mm.

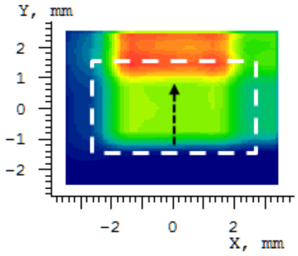


Figure 5. (a) The y-direction shift of projection pattern on LCoS for single G1 LED with $\theta_{microlens}$ of 10°.

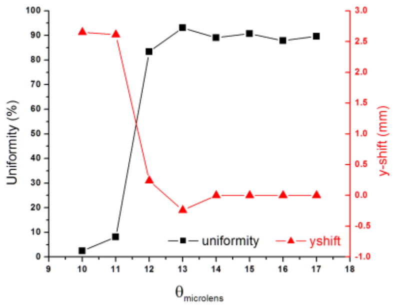


Figure 5. (b) The variation of uniformity and y-direction pattern shift on LCoS with $\theta_{microlens}$.

The optical utility of proposed non-imaging system on each component is listed in Table 1. And the flux efficiency on LCoS is 15.31 % with proposed components. With this efficiency of non-image system, the total flux efficiency of 10% would be achieved with the optimized image system that could be applied for embedded pico-projector.

Table 1. The optical utility of each component in proposed non-image system.

Components	Collimator lens	Microlens array	Condenser
Optical utility	99.36%	99.04%	72.62%

Conclusion

In this paper, we proposed a practical design of non-image LED illumination system within a compact volume of 34mm ×12mm × 12mm. And we present a substantial microlens array design to improve the optical uniformity and modify the beam direction shift caused by a planar light source. Optical properties including optical uniformity and optical utility are numerically analyzed by ray-tracing method. The final optical utility on the LCoS panel is 15.31% with uniformity of 84.75%. With this design and evaluation, the non-imaging system for pico-projector is compact and realizable.

Reference

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