Design and evaluation of illumination system for pocket projector using single element freeform optics with fly eye integrator

A. Dwivedi, S. K. Tiwari, G. S. Khan, A. Sharma, and C. Shakher

Indian Institute of Technology, Delhi, New Delhi, India

mailto: dwivedi.ashish1@gmail.com

For a projection system, uniform illumination at image modulator area with highest possible collection efficiency is a necessary requirement. There are systems which are able to achieve this goal by using multiple optical elements for light collection and separate module for homogenization thus posing challenging situations during minimization of system form factor, optical mounting, alignment and production cost . In this study, design concept of single element freeform optics integrated with fly eye lens is proposed for pocket projectors. Design of various derivative configurations are discussed with special considerations of manufacturability. Ray trace analysis is performed to evaluate different systems for ideal point source as well as for extended sources. Further, the scaling effect of the collection optics on system performance for extended sources is also discussed.

1. Introduction

With increase of video contents and high speed data connectivity; a handheld small size display systems capable to project images on a screen are on demand. For the realization of such pocket size devices image quality, optical engine form factor, manufacturability and cost are the challenging issues.

Recent advancement in solid state light sources in terms of optical efficiency, emitting surface area, long life time, and color performance makes them an ideal light source for projectors, provided an appropriate light collection unit is designed. In the conventional approach multiple lenses are required for light collection and collimation which increases form factor and cost [1]. One of the ways to reduce multiple elements is to use freeform collimator and fly-eye integrator for illumination [2]. For the construction of freeform surfaces there are number of methods which requires complex mathematical calculations for example SMS method [3]. A comparatively simpler method of freeform surface construction based on fundamental laws of refraction and total internal reflection (TIR) can also be used [4].

In this paper, a novel, compact, monolithic freeform optical element capable of light collection and homogenization based on fly-eye lens-let arrays is proposed.

2. Simulation approach

Illumination unit for projection system consist of optics for light collection and homogenization part for uniform illumination on the image modulator. Among two available homogenization components (light pipe and lens-let arrays) lens-let array is preferred for compact projectors [2]. For the light collection, a freeform lens can be used with refraction based central part on the opposite side of light source and TIR based peripheral part, designed for point source [4]. In our approach central part has been accommodated towards the light source so that the top surface will become flat with collimated rays coming out of it. This reduces the size of collimator equal to the size of TIR part. Further, on the top of the flat surface lens-let array can be integrated to make a single monolithic component (Figure1 and 2) as an illumination unit. The second lens-let array will be a separate part with rest of projection unit.

3. Compactness

It is observed that the segment connecting to central refraction part and TIR part can be modified to further reduce the overall footprint. This is done by using straight line connecting the central and TIR part (a cylindrical wall in 3D) instead of circular arc. The TIR part is also recalculated as per the modified incident rays. If this connecting line is parallel to freeform central symmetrical axis then all the rays for TIR will be refracted toward x-axis so that total height of TIR part will get reduced (Figure 3).

4. Scaling effect of collimation optics

The designed freeform surface is based on point source approximation, but the real light sources like LEDs are extended sources. Therefore the performance of the system will deteriorate if extended light sources are used. It is improved by scaling of collimation optics. The limit of the scaling is defined by size and the numerical aperture of lens-let array, as the degree of collimation should be within angular acceptance of lens-let arrays. Figure 4 shows the degree of collimation with scaling factor for point source and extended LED source (3.1 x 2.56 mm^2).

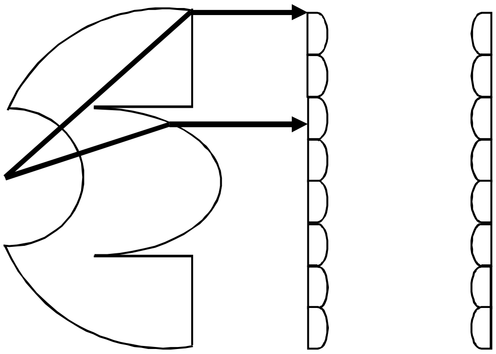

Figure 1: Typical freeform lens with fly eye integrators, central refracting part on opposite side of source.

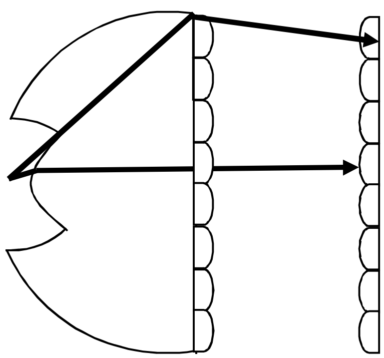

Figure 2: Freeform lens with integrated fly-eye lens and central refracting part towards light source.

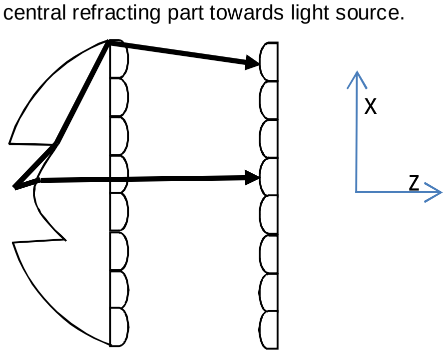

Figure 3: Modified compact freeform lens with straight connecting lines between central refracting part and TIR part.

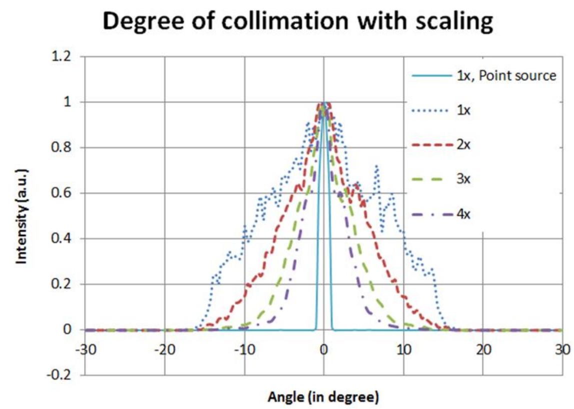

Figure 4: Effect of scaling on degree of collimation for point source (solid line) and 4 chips single LED (other dotted lines)

5. Conclusions

In this paper a new concept to reduce the size of pocket projector illumination unit is proposed. The designed monolithic component is having freeform based light collection optics integrated with lens-let array. The improvement in collimation performance by scaling of collimation optics is also studied. The designed illumination unit can be used in projection systems using single multi-chip LEDs as well as separate red, green and blue LEDs.

References

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