Designing a secondary optical freeform lens for signal lighting

M. Essameldin*, A. Alinoori*, D. Hilbig*, F. Fleischmann*, T. Henning*, W. Lang**

*Faculty of Electrical Engineering and Computer Science, Bremen University of Applied Sciences
**Institute for microsensors, -actuators and -systems, University of Bremen

mailto:mahmoud.essameldin@hs-bremen.de

For signal lights the intensity distribution is specified to meet the requirements regarding the brightness perception of users, not the illumination of an object. In this paper a new method of designing a secondary optical freeform lens is proposed. This method deals with the adaption of physical output properties to the requirements of signal lighting. The optical performance is investigated by using a numerical simulation. In addition, tolerance analyses are presented.

1 Introduction

For signal lights, luminous intensity (I_v) of light is specified to meet the requirements regarding the brightness perception of users, not the illumination of an object. Since light distribution of most LEDs is approximately lambertian, the I_v of LEDs must be redistributed to meet the requirements of each application. In this paper a new method of freeform lens design for signal lighting is proposed. It combines the advantages of both, the Tailor method [1] and the Source-Target mapping method [2].

2 Methodology and Lens Design

Procedures of designing a freeform lens surface can be divided into three steps as following:

2.1 Light-Energy solid angle mapping

Light-Energy solid angle mapping is used to derive the relation between the source light ray angle α_i and the required target ray angle α_o based on the principle of energy conservation [2]. The source and target $I_{v\,i\,\&\,o}$ distribution without any energy losses are presented in Fig. 1, where the volume is proportional to the total I_v (Equal volumes).

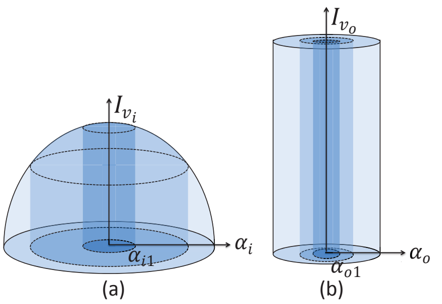

Fig. 1 *Geometrical representation of light-Energy solid angle mapping: (a) Light source parabola distribution over 45.0° (b) Circular uniform distribution over 22.5°.*

It is required to design a refracted lens to achieve a uniform circular I_v distribution over a solid angle $\pm 11.25^\circ$ using a light source with a parabolic I_v distribution over a solid angle $\pm 22.5^\circ$.

Based on the concept of energy conservation and the mathematical definition of integration, solid angle mapping can be described using

$$2\pi \int_0^{\alpha_{in}} I_{v_i}\, \alpha_i \, d\alpha_i = 2\pi \int_0^{\alpha_{on}} I_{v_o} \alpha_o \, d\alpha_o. \qquad (1)$$

By setting the solid angle (Independent parameter) as the radial value, the required I_{vo} distribution can be determined directly by changing the values of the azimuth angles $0 \le \alpha_i \le \alpha_{in}$ to the required refracted angles $0 \le \alpha_o \le \alpha_{on}$, where n is number of the mapping angles. The distance between an object and light source has no influence on the calculations compared to [1, 2], because the aim is not an object illumination.

2.2 Determining the freeform points

As shown in Fig. 2(a), the first surface of the lens is a spherical surface in which the light source is placed at the center of curvature. The freeform surface is responsible of refracting the light rays from α_i to the required α_o. The differential equation

$$\frac{ds(\alpha_i)}{d\alpha_i} = \frac{-\sin(\alpha_i - \alpha_o)}{(n_i/n_o) - \cos(\alpha_i - \alpha_o)}\, s(\alpha_i) \qquad (2)$$

is used for determining the surface sag (s) [3]. It describes the freeform sag as a function of α_i, where n_i is the refractive index of the lens (PMMA) and n_o is the refractive index of the air. Fig. 2(b) shows the 2D freeform sag using formula (2).

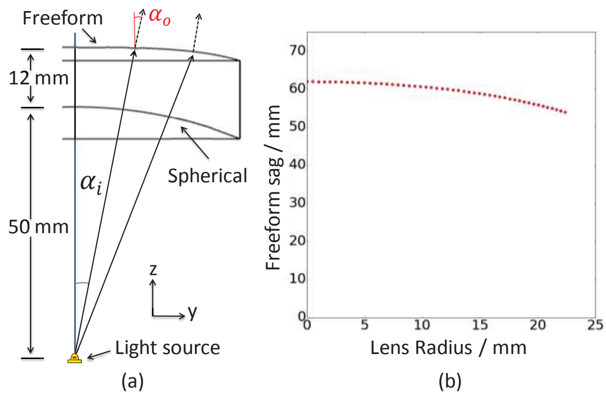

Fig. 2 *(a) Simulation setup (b) Constructed freeform sag.*

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2.3 Constructing the freeform surface

Freeform lens can be constructed by using the biconic zernike lens in Zemax OpticStudio [4].

3 Simulation Results and Performance Analysis

In this section, the optical performance of the lens is investigated using a numerical simulation of optical ray tracing [4]. The I_{v_o} distribution is shown in Fig. 3. The simulation results show a high degree of uniformity as shown in Fig. 4(Black curve).

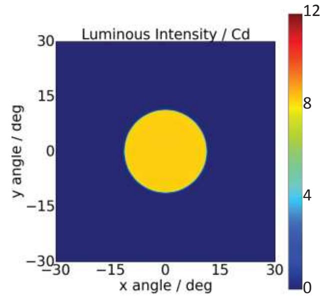

Fig. 3 *Simulation results - Luminous intensity.*

4 Tolerance Analysis

By translating the light source in the +z direction, the light rays refracted with smaller angle values compared to the mapping values. Therefore, I_v distribution becomes more dense at the middle region as shown in Fig. 4(Blue curve).

By translating the light source in the -z direction, the refracted angle values become greater than the required values. Also total internal reflection (TIR) occurs at the lens side. Thus, I_v distribution becomes more dense at the side regions as shown in Fig. 4(Red curve).

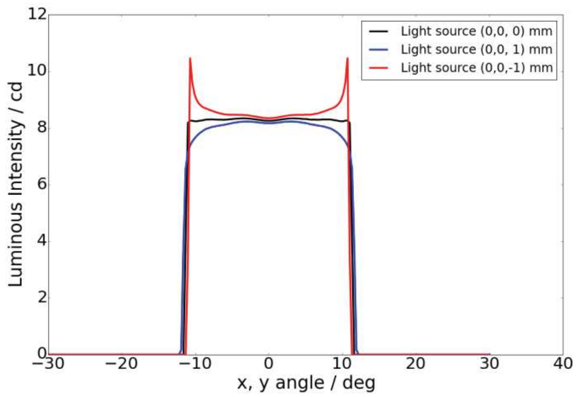

Fig. 4 *Luminous intensity by translating light source in ±z.*

By translating the source in the +x direction, each ray follows one of the following three cases. The first case is backward TIR at the freeform surface. The second possibility is TIR at the lens side. The third case is a deviated refracted angle value from the mapping angle value.

Based on the possible three cases due to the light source translation in the +x direction, the number of the output positive angle rays becomes greater than the number of the output negative angle rays as shown in Fig. 5.

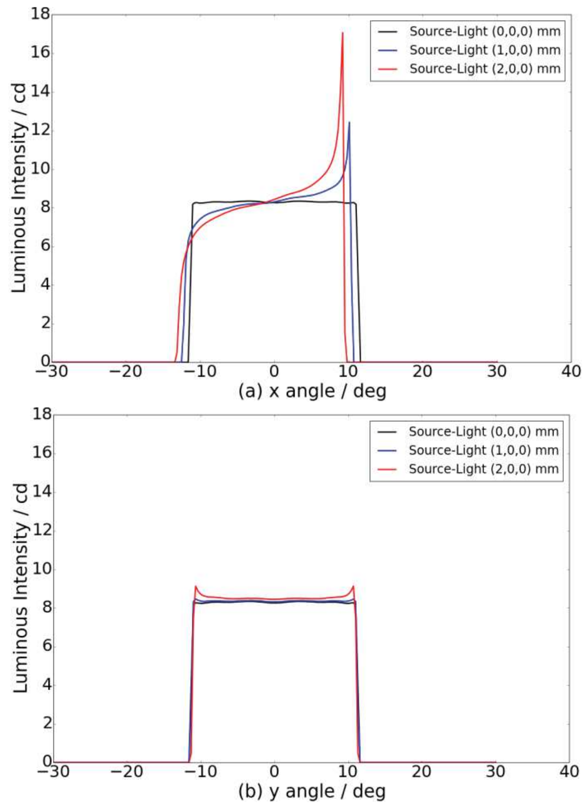

Fig. 5 *Luminous intensity by translating light source in +x (a) Cross section row and (b) Cross section column.*

5 Conclusion

In this paper, the required procedures to design a freeform refracted lens has been discussed. The simulation results show a high degree of uniform luminous intensity distribution. The influence of misalignment between the freeform lens and the optical source has been explained. Finally, this paper combines the concepts of light-energy solid angle mapping, energy conservation and partial differential equation in designing a lens for signal lighting applications.

References

[1] Zhenrong, Z., Xiang, H., and Xu, L., “Freeform surface lens for LED uniform illumination,” Applied optics 48(35):6627–6634 (2009)

[2] Chen, J.-J., Huang, Z.-Y., Liu, T.-S., Tsai, M.-D. et al., “Freeform lens design for light-emitting diode uniform illumination by using a method of source-target luminous intensity mapping,” Applied optics 54(28):E146-52 (2015)

[3] Moiseev, M.A. and Doskolovich, L.L., “Design of TIR optics generating the prescribed irradiance distribution in the circle region,” J. Opt. Soc. Am. A 29(9):1758 (2012)

[4] OpticStudio (15.5), Zemax, LLC, http://www.zemax.com/ (2016)