Design methods for uniform illumination light device using LEDs

Boundary center matching & distribution approximation

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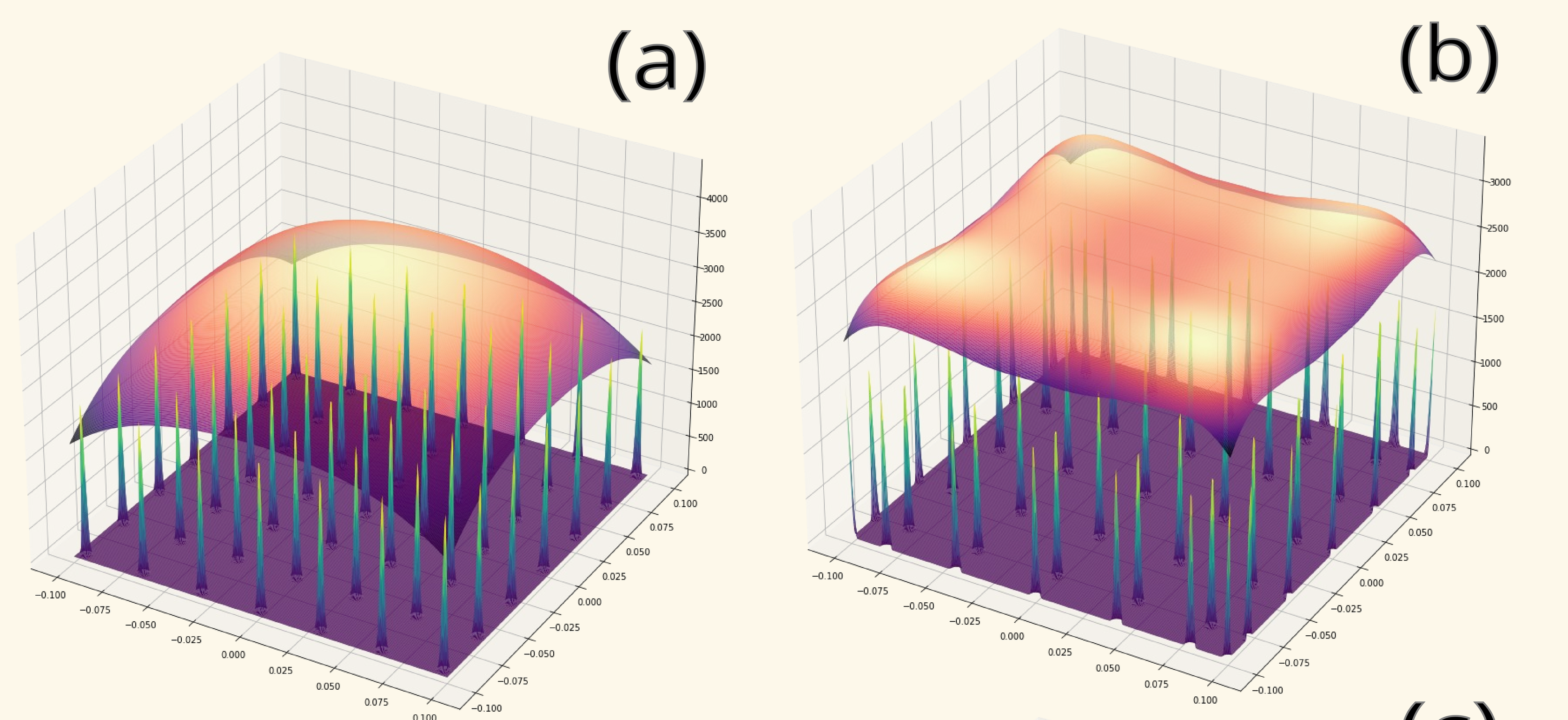
Introduction

- Uniform illumination light devices are applicable for many fields, however, design using point sources showing inhomogeneous irradiation requires a lot of effort to achieve the desired uniformity.
- Sparrow's criterion method and its expansion(ESC) can provide high flat illumination near the center region[1]. However, rapidly decreasing illumination near the boundary reduces overall uniformity. In addition, it does not consider target region size, only focusing on its center area.
- Meta-heuristic methods show improved results than criterion but they depend on initial conditions critically on the number of sources[2-3].
- This paper proposes two methods for designing uniform illumination devices.
  - ***Boundary center matching*** (BC) method is an expansion method for the given region to redeem a boundary decreasing.
  - ***Distribution approximation*** (DA) method approximates source distribution by solving an integral equation and estimates source number and location with kernel estimation.



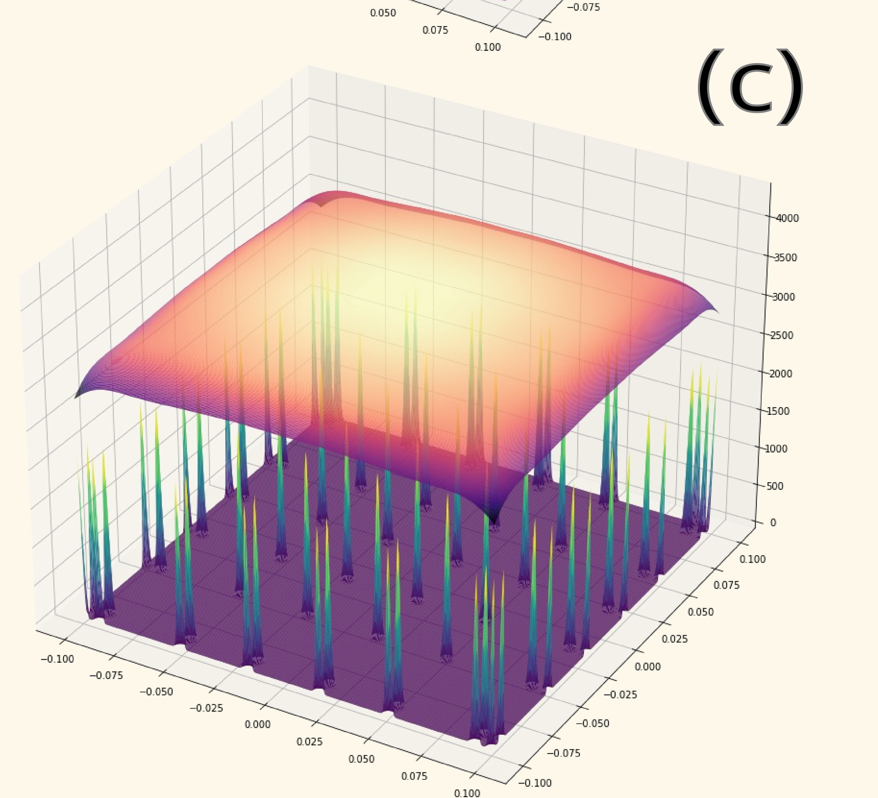


Figure. 1: Simulations of illumination. Below planes of each the sub-figures indicate the distribution of sources and above graphs are illumination map of the target plane.
(a): The ESC method,
(b): Filling Q region with the ESC method and conducted the BC matching expansion,
(c): The DA method.

Methods

n : Number of LEDs
x : Position on LED plane
$I(x,t)$: Intensity for t position for x location LED
t : Position on target plane
W : Width of plane
H : Gap between two given planes
$D(W/H;x)$: Difference between boundary and center intensity induced by x, -x pair source.

Boundary center matching

Divide into 3 regions

$$\overset{P}{(0,x_m)},\overset{Q}{[x_m,x_e)},\overset{R}{[x_e,W/2)}$$

Fill Q region

$$\{x_i\}_i^{n/2} \in Q$$

Expand to R region

$$\sum_i^n I(0,x) = \sum_i^n I\left(\frac{W}{2},x\right)$$

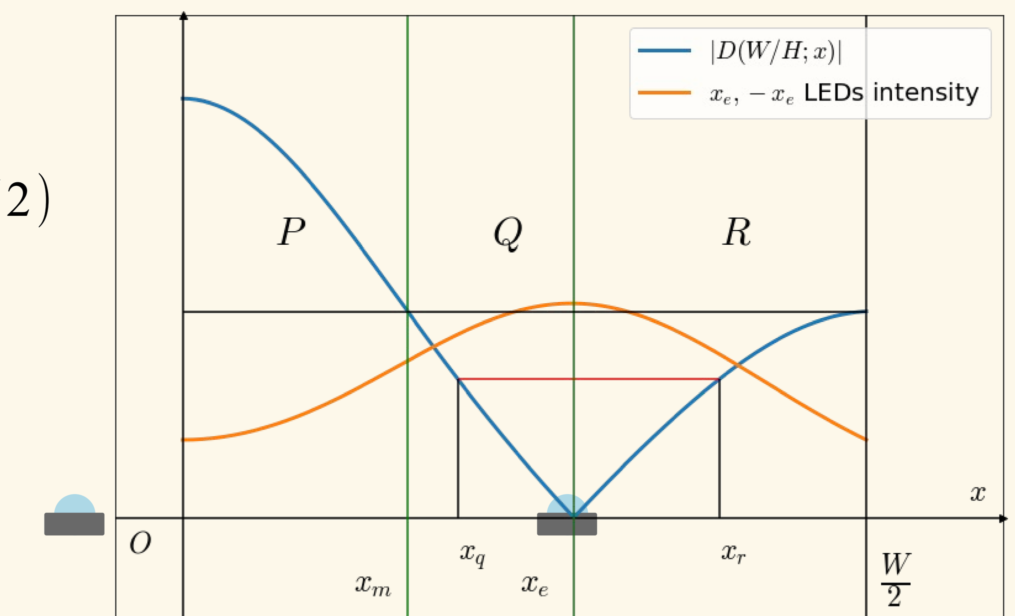


Figure. 2: Graph of intensity difference between center and boundary points induced by the two pair of sources and intensity graph induced by x_e, $-x_e$ location pair source, x_m: $D(W/H; x_m) = D(W/H; W/2)$ point, x_e: root of $D(W/H; x)$, x_q: the point in Q region, x_r: the point in R region.

Distribution approximation

Integral equation

$$I(\{x_i\}_1^n,t) = \int_{-W/2}^{W/2} K(x,t)\sigma(x)\,dx$$

$$I(\{x_i\}_1^n,t) = I_0$$

Hard to solve directly

$\Delta x, \Delta t$

Discretization

$$\boldsymbol{K}\vec{\boldsymbol{\sigma}} = I_0\vec{\mathbf{1}}$$

$\vec{\boldsymbol{\sigma}}$

Kernel estimation

$$\frac{1}{\sqrt{2\pi}\,h}\sum_i^n \exp\left(\frac{(x-x_i)^2}{2h^2}\right) \approx \vec{\boldsymbol{\sigma}}$$

$\{x_i\}_i^n$

Solution

$$\sigma(x) = \sum_i^n \delta(x-x_i)$$

Results and Discussion

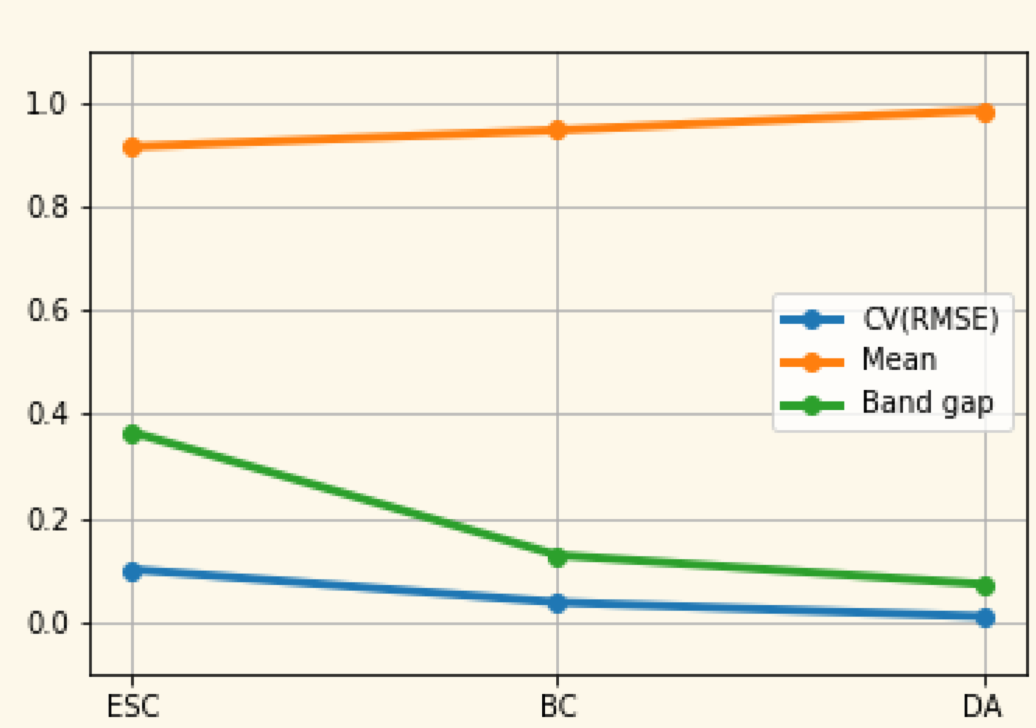


Figure. 3: Compare of uniformity factors of the above Simulations. Each factors are calculated with normalization. The band gap means difference of the maximum and the minimum intensity.

1. The simulations were calculated based on a perfect Lambertian model and a condition that $(W/H) = 2$.
2. Both BC and DA methods showed improved overall uniformity for the given target area and the result of the DA method was a better result than the BC method, however, the BC method has an advantage in calculation efficiency.
3. The result of the BC method has multiple local maximum points between the center and boundary region. If there are significantly sensitive properties, in device application, by intensity values, there is no benefit to raising uniformity using the BC method. In this case, even if there is spatial loss, a large source array computed by the ESC method could be more appropriate.
4. The result of the DA method provided the highest uniform illumination distribution. Its number estimation relies on the kernel estimation method. This process is focusing on estimating the number of sources but could apply to power allocation.

Conclusion

1. This paper suggested two new methods for designing uniform illumination devices. Both methods showed better performance than the previous ESC method.
2. The BC matching method requires other methods that fill center region to expand to outer boundary. It guarantees that center and boundary has illumination value, however, the middle region can show convex shape.
3. The efficiency of the distribution approximation depends on the kernel estimation process for obtaining a discrete distribution. It is focusing on the determination of source number but can be also applicable to power allocation of the given array of sources.

References

1. I. Moreno, M. A. no Alejo, and R. I. Tzonchev, "Designing light-emitting diode arrays for uniform near-field irradiance," Appl. Opt. 45, 2265–2272 (2006).
2. Zhouping Su, Donglin Xue, and Zhicheng Ji, "Designing LED array for uniform illumination distribution by simulated annealing algorithm," Opt. Express 20, A843-A855 (2012)
3. Sourav Pal, "Optimization of LED array for uniform illumination over a target plane by evolutionary programming," Appl. Opt. 54, 8221-8227 (2015)

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