Virtual Mechanism for Displaying Viewing Angle Related Mura of a Backlight Unit in Simulation

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Abstract

We have devised a methodology based on the concept of foveal (or parafoveal) vision to investigate viewing angle related mura of a backlight unit (BLU). Three different cases of mura phenomenon in BLUs are studied with optical simulation software ASAP in this work. Simulation results, illuminance comparisons between emitting light from BLUs without and with "angle sorting" as well as experimental results are presented. They show good agreement between simulations and experimental observations that demonstrates the method's validation and robustness.

1. Introduction

Mura detection in a backlight unit (BLU) is performed by either instruments or mostly by human eyes mainly in the stage of manufacture and prototypes testing. But in some cases it is still difficult to make a precise determination of mura by the above means, especially for viewing angle related ones. Though progress has been made in automatic inspection by incorporating human vision model like Spatial Standard Observer (SSO) [1]. However, the issue of viewing angle related mura is still very much in need of exploration. On the other hand, how to locate the viewing angle related mura can be very important in the optical design phase of a BLU in order to enhance the competing edge in terms of developing costs and time. To date, however, there is little work being done to address this need; particularly, optical simulations in a BLU design are supposed to provide a way of discovering viewing angle related mura. But almost no related research is found in the literature since common illuminance output data contains information of light rays with all available emitting angles in optical simulations of BLUs.

Now this issue can be resolved by means of optical simulations using Advanced Systems Analysis Program (ASAP) [2]. We have devised a methodology based on the concept of foveal (or parafoveal) vision to directly visualize viewing angle related mura in a BLU simulation. In order to illustrate the validation and suitability of our devised methodology, three cases of viewing-angle related mura in BLUs are examined by optical simulations using ASAP in this work. There are hot spots with cross-pattern in an edge-type LED BLU with a longitudinal V-groove LGP, "bright fringes" in a wedge-type CCFL BLU with a longitudinal V-groove light-guide plate (LGP) [3], and lamp mura in a direct-type CCFL BLU, respectively. Simulation results demonstrate that the method is right for the unveiling of viewing angle related mura in a BLU design by using optical simulations. However, only some of those experimental observation and simulation results when BLUs viewed at the normal viewing angle are presented in this work.

2. Methodology

With a mid-size (13 to 15 inches diagonal) BLU held 25 cm (near point) away while mura inspection is carried out, the visual angle is limited to within $\pm 20^\circ$. On the other hand, as we know that both the visual acuity and contrast sensitivity of human vision decline with the increase of retinal eccentricity [4]. Then it is plausible to suppose that human perception can be represented as foveal (or parafoveal) vision, visual angle of $\pm 10^\circ$, if an object is fixed and focused on the area of fovea and its surrounding of a viewer which is quite comparable to a situation that specifically occurs in BLU inspection by human eyes. The above facts form the theoretical foundation of our devised methodology: using the "selected" emitting light rays with pre-assigned angular distribution (for instance, solid angle of $\pm 10^{\circ}$) from a BLU in optical simulations, roughly corresponding to the visual angle of foveal (or parafoveal) vision, to directly visualize the viewing angle related mura.

In order to substantiate the validity of above postulate, a reduced eye model is constructed which is based on the Indiana reduced eye model [5]. In our application, the Indiana reduced eye model is further extended by specifying the size of fovea together with its surrounding area. The link between foveal (or parafoveal) vision and "angle sorting" light rays in optical simulations can be demonstrated easily by examining our modified Indiana reduced eye model using ray-tracing, as shown in Fig. 1. The test results support the postulate that the visual angle of foveal (or parafoveal) vision can correspond to the "sorting angle" of emitting light from a BLU in an optical simulation. Therefore, we assume that the angular range of emitting light rays from a BLU are "selected" to be $\pm 10^{\circ}$ in simulations in order to mimic foveal vision. In addition, the normal viewing angle is assumed when BLUs are "seen". The cases of oblique viewing angle are not in the scope of this work.

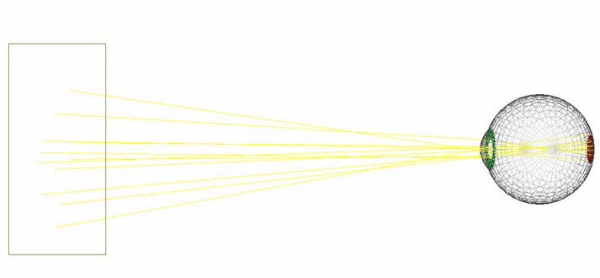

Fig. 1. Illustration of modified Indiana reduced eye focusing light rays from a display onto the fovea and its surrounding by ray tracing.

3. Results and discussion

The first case studied by our devised method is an edge-type LED BLU with longitudinal V-groove structures in the bottom end surface and rough surface in the emitting end surface of a LGP as well as a reverse prism film on-top. A corresponding ASAP ray-tracing model is constructed, as illustrated in Fig. 2. There exists an area of LGP immediately adjacent to LEDs covered by no optical film. However, in order to minimize the factors that can complicate the interpretation of

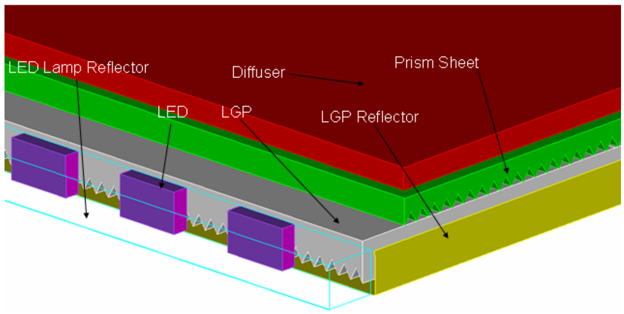

Fig. 2, A schematic of an edge-type LED BLU with longitudinal V-groove structures on a LGP using a reverse prism film.

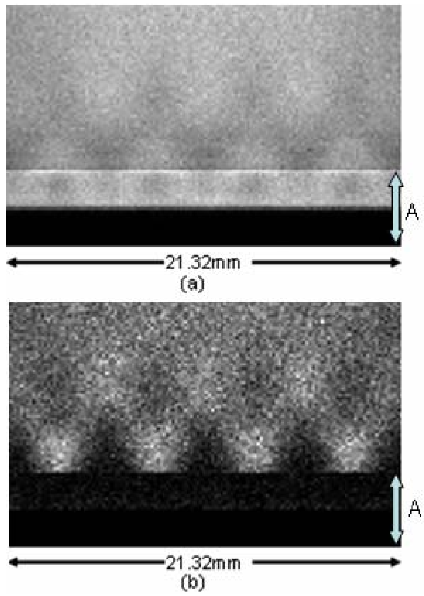

Fig. 3. Simulation results of illuminance distribution for emitting light from a LED BLU (a) without and (b) with "angle sorting" of light rays.

simulation results as well as to reduce computation time, there is no diffuser film presented while simulations are performed. The number of LEDs used in simulations is limited to only 5 due to a trade-off between computation time and degree of illustration of mura. A typical simulation result isshown in Fig. 3(a), an emitting light output from a BLU presented in terms of illuminance which is a common practice. By comparison with Fig. 4, it appears that this common approach for presenting simulation results fall short of accuracy. Since the light output from a BLU encompasses emitting light rays propagating toward almost every available direction which cannot be equivalent to those ones that enter human eyes or a CCD camera. By "selecting" the light rays confined to certain

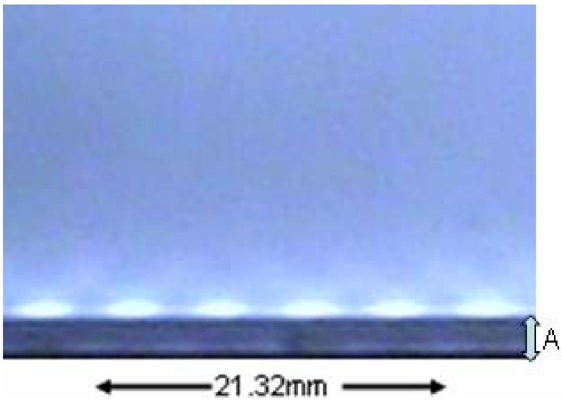

Fig. 4. Image of hot spots plus cross pattern in a LED edge-type BLU with longitudinal V-groove structures on a LGP using a reverse prism film.

solid angles (±10°) in simulations, corresponding to the visual angle of a human eye or a CCD camera, we can faithfully demonstrate viewing-angle related mura, as shown in Fig. 3(b), which can be directly linked to the captured image from a CCD camera in Fig.4.

"Bright fringes" in a wedge-type CCFL BLU with longitudinal V-groove structures on the bottom end surface and surface roughness on the emitting end surface of a LGP, as shown in Fig. 5, is the second case to be studied. The schematic diagram is depicted in Fig. 6. Same to the previous case, surface roughness is created by sandblasting in the emitting end surface of the LGP. Besides, surface roughness is produced in the incident end surface of a LGP by the employment of end surface cutting which is a common practice to reduce the mura—bright fringes. By our previous investigation, the cause of optical phenomenon of

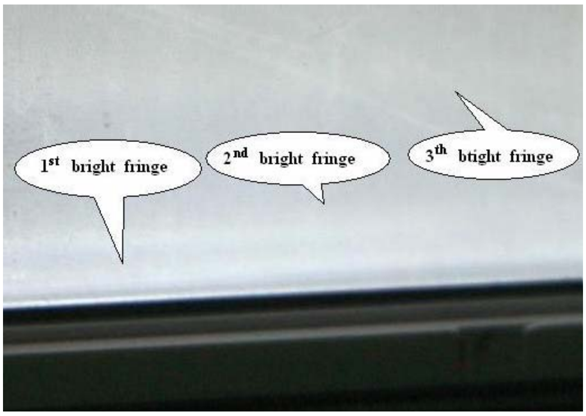

Fig. 5. Image of successive bright "fringes" near the incident end surface of a wedge-type LGP with longitudinal V-groove structures in an edge-type CCFL BLU.

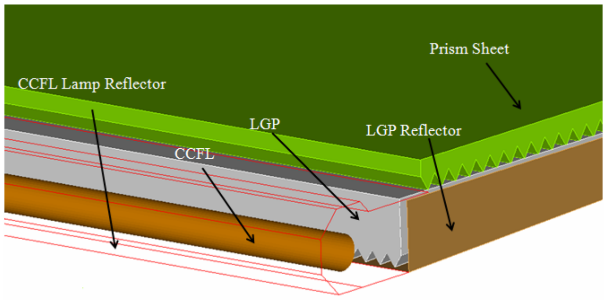

Fig. 6, A schematic of a wedge -type CCFL BLU with longitudinal V-groove structures on a LGP, and a reverse prism film implemented.

"bright fringes" is due to light leakage into the gap region which is formed between the light transmitting (reflecting) surface of a LGP and the distal end portion of lamp reflector (reflection film) after the assembly of a BLU. However, the "bright fringes" is viewing-angle related and can only been "seen" by our devised method in simulation. The above statement can be verified from the results of simulation. In Fig. 7(a), without "angle sorting", it appears that the smearing effect of roughness in the incident end surface of a LGP seems to be working in simulation. However, with the implementation of "angle sorting", the "bright fringes" reemerges in simulation, as shown in Fig. 7(b), which is quite comparable with the CCD image of "bright fringes" in Fig. 5.

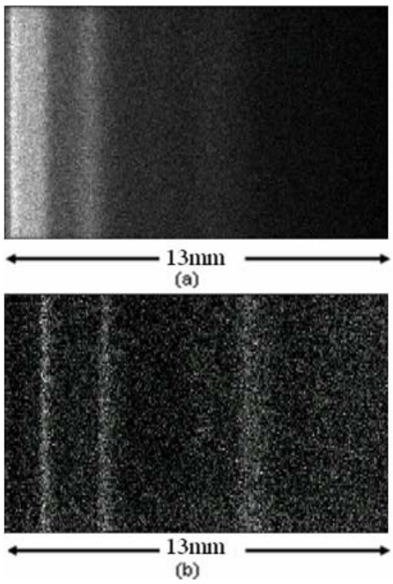

Fig. 7. Simulation results of "bright fringes" of a CCFL BLU with longitudinal V-groove structures and surface-roughening incident end surface in a LGP (a) without and (b) with "angle sorting" of light rays.

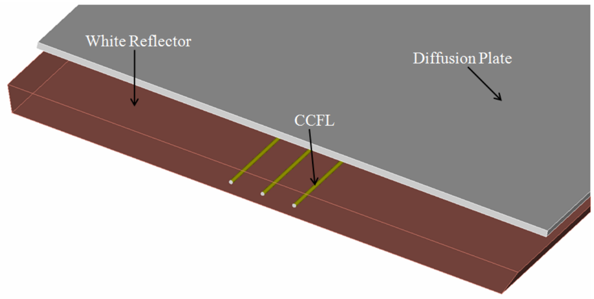

Fig. 8, A schematic of a direct-type CCFL BLU.

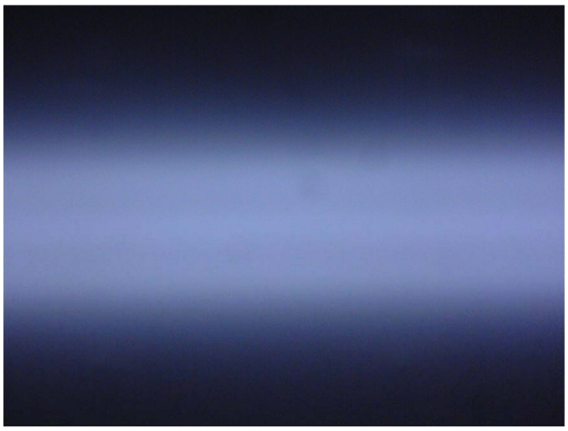

Fig. 9. Image of lamp mura in a direct-type CCFL BLU.

The last case to be examined is that of lamp mura in a direct-type CCFL BLU. An ASAP ray-tracing model of a direct-type CCFL BLU is shown in Fig. 8. Due to the concerns of computation time, only three CCFL lamps are employed in simulations, and there is no optical film on the top of diffusion plate as well. The image of lamp mura with only three CCFLs lightened in a direct-type CCFL BLU is shown in Fig. 9. A typical set of simulation result, as shown in Fig. 10, demonstrates, not so quite surprisingly, that there is not quite a difference on lamp mura between emitting light rays from a direct-type CCFL BLU with and without "angle sorting". This can be explained that the emitting light output from a direct-type CCFL BLU is Lambertian, it is not specific viewing-angle related, even lamp mura is considered to be luminance non-uniformity. But this might imply that further effort is needed to improve the accuracy of the devised method. However, mura in a BLU can be specific viewing-angle related as demonstrated by the first two cases. This has clearly demonstrated the ability and potential of our devised methodology for exploring optical phenomena by optical simulations.

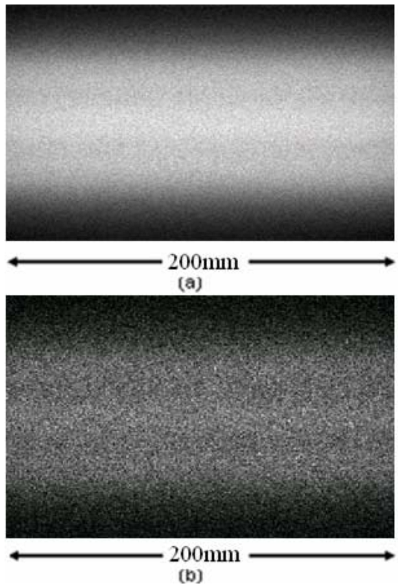

Fig. 10. Simulation results of lamp mura in a direct-type CCFL BLU (a) without and (b) with "angle sorting" of light rays.

4. Summary

A methodology using "angle sorting" technique based on the concept of foveal (or parafoveal) vision for visualizing viewing-angle related mura of a BLU in optical simulations is devised. Three types of mura in BLUs are examined. They demonstrate the value and potential of this devised method. Further work is needed to improve the accuracy of this method.

Acknowledgement

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5. References

1. A. B. Watson, SID'06 Technical Digest, p.1312 (2006).
2. Breault Research Organization, http://www.breault.com/.
3. C. C. Huang, C. C. Kang, J. F. Lin, and F. Y. Chou, IDMC'07 Technical Digest, p.652 (2007).
4. T. Wertheim, Am. J. Optom. Physiol. Opt., **57**[12], p915 (1980).
5. L. N. Thibos, M. Y. Faao, X. X. Zhang, and A. Bradley, Optom. Vis. Sci, **74**[7], p548 (1997).