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The approach for autodesign of optical characteristics of different illumination units such as backlight systems, led arrays and light boxes is considered. Suggested software solution allows finding optimal configuration of lighting scheme for providing necessary distribution of output light. Additional preprocessing phase is introduced in design process, which provides reduction of design iterations and better convergence compared to conventional design methods, utilizing random fluctuations of design parameter between iterations. The results of several designs of different kinds of illumination systems are presented.

Keywords: backlight system, autodesign, illumination distribution, LED, microstructure

1. Introduction

LEDs have a lot of advantages over traditional light sources like incandescent, halogen and luminescent lamps. High brightness, small size, excellent durability and wide range of available colors makes them perfect choice for different kind of illumination systems. However, small emitting area and very high luminance complicate design of LED based illumination systems which emission has to be spatially uniform for a wide area. Usually these LED based illumination system applies so called backlight scheme of the redistribution of the LED emission to wide area. Main design target of backlight unit of any device (mainly it is used for liquid crystal displays[1)]) contributes to dropping energy consumption and increasing output brightness. In addition, taking ergonomics requirements into account (such as uniformity of display brightness, spatial and angular, spectral characteristic) we have a really sophisticated design problem.

Design features of backlighting units may differ from one vendor to another. However general unit schemes remain close to each other. High and uniform brightness is provided by optimal set of scattering microstructure parameters. Usually side-illuminated backlight microstructure is located on bottom reflector plane and desired light distribution is achieved by tuning shape of microelements, their orientation, size and properties.

In the paper the developed solution of backlight autodesign is considered. It is illustrated by examples of backlight system used for different kinds of lighting applications such us illumination of automotive speedometer of car dashboard, indoor and outdoor illumination. The example of the car dashboard scheme is presented in Fig. 1. The system is illuminated by two LED. Light enters guiding plate, propagates there and exits it due to scattering on microelements (like dimples, diffuse dots, or others). Leaving guiding plate the light illuminates speedometer face with scale and digits drawn on it. This technique of the light propagation is a common for most of backlight systems, including backlights for indoor and outdoor illumination: light from LEDs enters to the backlight, propagates inside of backlight, scatters on the microstructure and after the number of scattering, reflection and refraction events leaves the backlight.

Light while traveling through device experiences deterministic total internal reflections and multiple scatterings on microstructure elements, thus making entire light distribution process stochastic. To compute such systems Monte-Carlo ray tracing methods are used. Main peculiarity of these computation methods is presence of white noise in resultant distribution.[2)] To reduce noise amount longer computation time is needed. On modern high-end clusters acceptable levels of noise can be reached within hours. It makes estimation of influence of microstructure parameters (which can be thousands or even millions) on final luminance distribution next to impossible. Therefore the ordinary optimization methods are useless here. On the other hand, microstructure parameter influence is usually local, that is only small area of output display is affected by certain element. Also we can considerably reduce the number of designed parameters by uniting elements into groups with the same parameter value, like dimple size. This was used for proposed optimization method which is similar to approach[3)] but has a number of special features allowing to speed up and improve design quality for number of types of backlight units.

2. Principle

Optimization method is composed of two phases: design pre-processing and optimization phase. In difference from conventional optimization systems (described in Ref. 3, for example) three suppositions are considered: firstly, we

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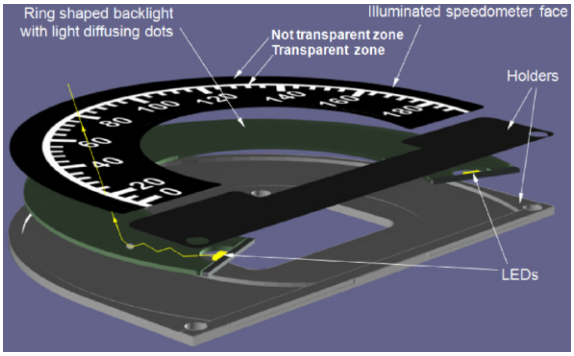


Fig. 1. (Color online) Scheme of the car dashboard speedometer.

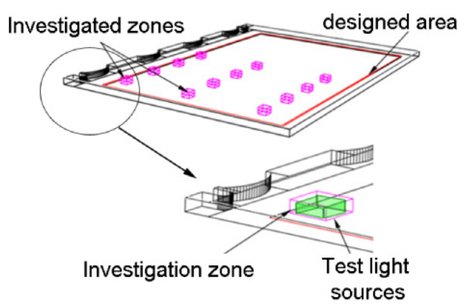


Fig. 2. (Color online) Scheme of LED backlight laptop screen with preprocessing zones highlighted.

suppose that design zone is subdivided in finite number of sub zones with constant design parameter value of microstructure (greater subdivision provides better results but greater calculation time); secondly, we consider only zero-order influence zones (backlight areas just above the designed cell) and first-order influence zones (backlight areas above four neighbor cells); thirdly, in design process described there is special pre-processing phase (unlike conventional design processes). During pre-processing phase very limited number of zones is investigated to determine influence function and after it the main design is started. Estimation of influence coefficients in separate phase is not that expensive in terms of resources and time, and much more effective then performing the same action during main optimization phase. Test zones are selected basing on device symmetry and light source characteristics. Pre-processing starts with calculation of selected areas response to different microstructure parameters. For this purpose test light sources are placed around the zone illuminating it with various intensity, thus influence function for test zones is obtained. Influence function for other zones is interpolated. Scheme of typical LED-illuminated laptop screen with test zones are demonstrated on Fig. 2.

The main phase is composed of three different cyclic actions:

- For existing (initial at first cycle) microstructure the output display luminance and each parameter zone illumination are computed.
- The deviation from target output distribution is estimated in form of RMS and if the deviation is acceptable then the process stops. If not then new parameter values are calculated with following assumptions: using the influence coefficient (calculated during pre-processing phase) and redetermination of influence coefficient conducted during computation action.
- Accordingly parameter values are changed and first action is performed again.

Several iterations are needed due to system nonlinearity and starting assumptions. In real systems each parameter zone influences distance areas of backlight. Currently optimization algorithm is restricted to only one parameter distribution can be designed: it can be chosen from size, density, orientation or some other parameter of dimples. But in most of practical cases one design parameter is sufficient to do efficient and high quality design.

The autodesign program module is integrated with SPECTER optical simulation software.[4)] This integration is very useful for the autodesign tool because of it allows using all features of SPECTER software like import of backlight device construction defined in CAD data, using libraries of LED (or other light sources), optical properties of materials, etc. All these features make results of the autodesign really applicable for manufacturing of backlight devices.

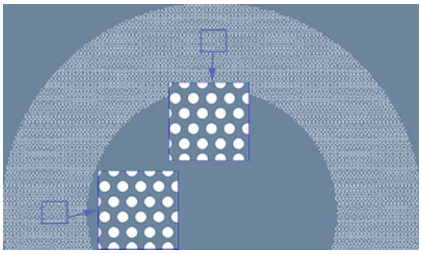
3. Speedometer Backlight Design

Autodesign of the speedometer backlight was performed by elaborated software. The speedometer possesses complex contour of output display and requires high uniformity rate to provide the device visibility under different environment illumination conditions. In this optimization process the density of elements was designed. The design goal is to reach uniformity of luminance distribution (allowed deviation has not to exceed 10%) of all illuminated area and increase average luminance of speedometer of car dashboard. Initial density distribution of microelements is shown in Fig. 3(a). Lighting simulation with initial scene produces output luminance of speedometer presented in Fig. 3(b).

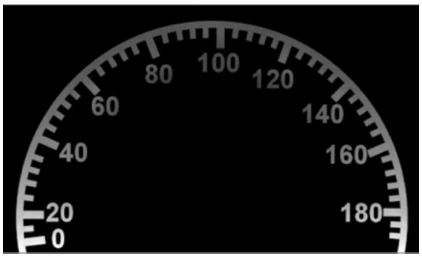
In the result of seven design steps (total time — 1.5 h for modern Intel Xeon workstation) the speedometer luminance distribution became uniform [Fig. 4(b)]. It should be noted that not only uniformity but also overall system efficiency is improved. The reason of efficiency improvement can be seen in Fig. 4(a): final dimple distribution corresponds to transparent zone of speedometer. It means that light is maximally focused on speedometer scale and digits illumination that allowed increasing average speedometer luminance in about 2 times (up to 1350 nit).

The design process convergence is shown in Fig. 5. It is seen that good design result is reach after the 4th design step while after 7th design step the required quality is reach and the following design steps do not improve the result.

The advanced of the proposed optimization solution in comparison with other methods is higher convergence speed and higher quality of final design result. Unfortunately detail description of similar design methods is absent in open sources so it is only possible to suppose the reason of

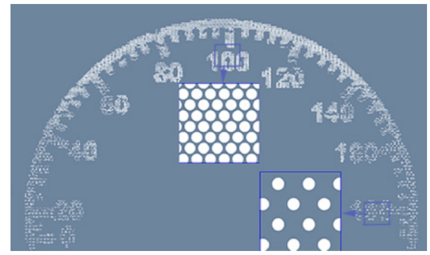


(a)

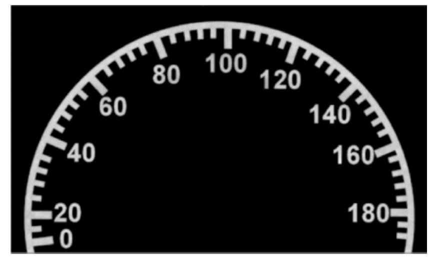


(b)

Fig. 3. (Color online) Dimple distribution: (a) initial dimple density distribution of speedometer; (b) initial speedometer luminance distribution.



(a)



(b)

Fig. 4. (Color online) Luminance distribution: (a) designed dimple density distribution of speedometer; (b) designed speedometer luminance distribution.

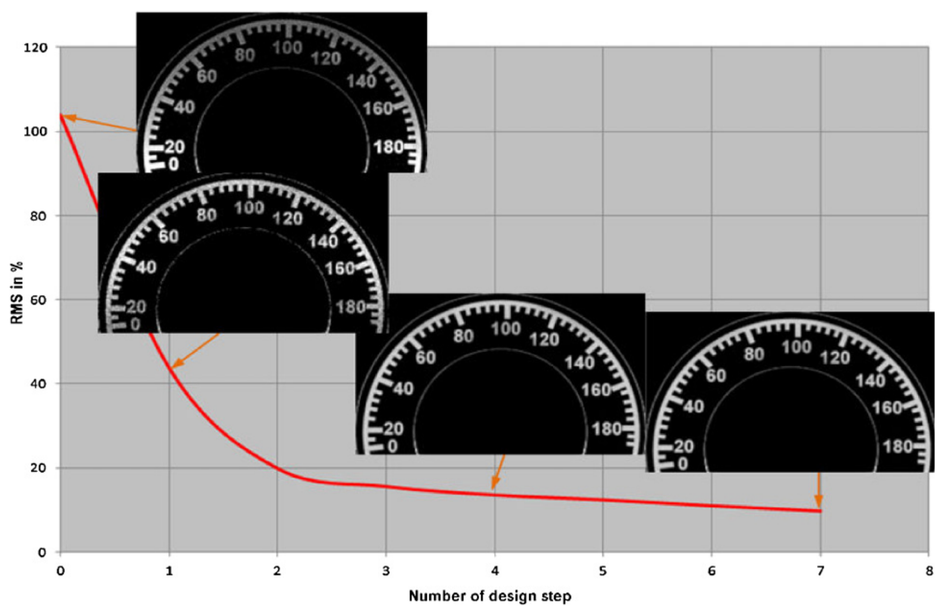


Fig. 5. (Color online) Speedometer design convergence chart.

difference is caused by preprocessing phase allowing accurate estimation of influence of response of microstructure parameter modification on the design target.

4. LED Luminaries for Indoor Illumination

Similarly to backlight system used in LCD displays the main requirements to luminaries used for indoor illumination are high power and high degree of uniformity of output light emitting: as spatial as well angular, moreover the energy consumption problem is very important too. The scheme presented in Fig. 6 is an example of the backlight indoor illumination system. Two LED arrays illuminate the light guiding plate faces and specially designed microstructure on the bottom side of the plate has to provide required spatial and angular distribution of output light emission.

The current design goal is to reach uniformity of the spatial luminance distribution (allowed deviation has not to exceed 3%) of all illuminated area and increase average luminance of backlight panel. Design of angular distribution is not considered in the paper. It was separate design which found optimal shape of microstructure element and then

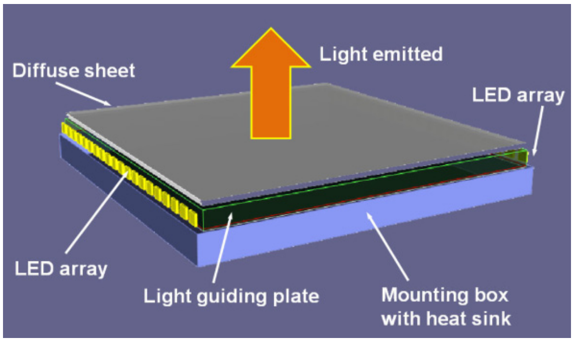


Fig. 6. (Color online) Scheme of indoor illumination system.

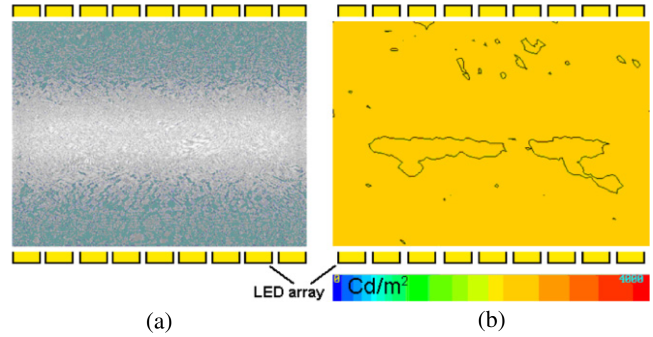


Fig. 7. (Color online) Indoor luminaire: (a) distribution of the microstructure elements; (b) and the luminance provided by luminaire with designed microstructure.

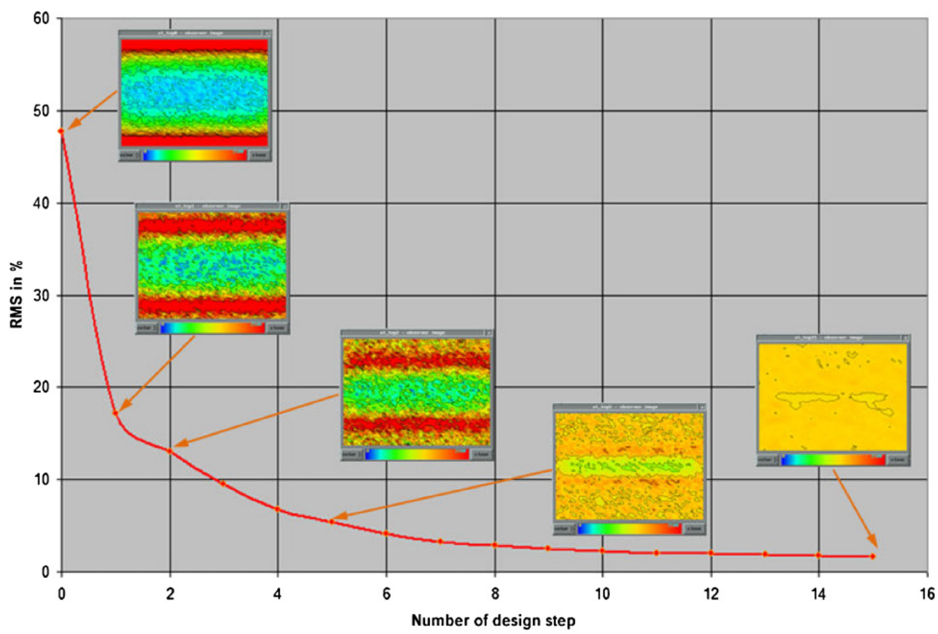


Fig. 8. (Color online) Indoor luminaire design process convergence.

is used in this design. Similarly to the design of the speedometer of car dashboard the optimization parameter was density of the distribution of the microstructure elements.

In the result of 15 design steps (total time — 1 h for modern Intel Xeon workstation) the indoor backlight reaches optimal relation between spatial uniformity of the luminance distribution and value of average luminance [Fig. 7(b)]. This result is provided with the distribution of microstructure elements shown in Fig. 7(a): maximal density of the microelement is in the middle of the backlight panel allows redistributing emission from the edge to the central zones of the device.

The design process convergence is shown in Fig. 8. It is seen that good design result is reach after the 5th design step while after 15th design step the required quality is reach and the following design steps do not improve the result.

5. LED Luminaries for Outdoor Illumination

Outdoor applications of LEDs are caused by high LED durability, energy efficiency and high brightness. The main aim of outdoor illumination system is to provide necessary level of illumination over certain area. This task is similar to the task of classical backlight design (with exception that result is illumination distribution in the far zone from the luminary) and the same autodesign tool can be used to reach the main design goal. An example of road illumination with LED street luminary is presented in Fig. 9. A construction of luminaire consists of LED and lens arrays. Road sizes, maximal overall dimensions of luminaries and their placements are fixed.

The purpose of simulation is to provide minimal level of illumination (no less than 12 lx) on the rectangular road region with size $40 \times 7\,\mathrm{m}^2$. Initial LED illumination system consists of 12×24 LEDs parallel to the road and provides

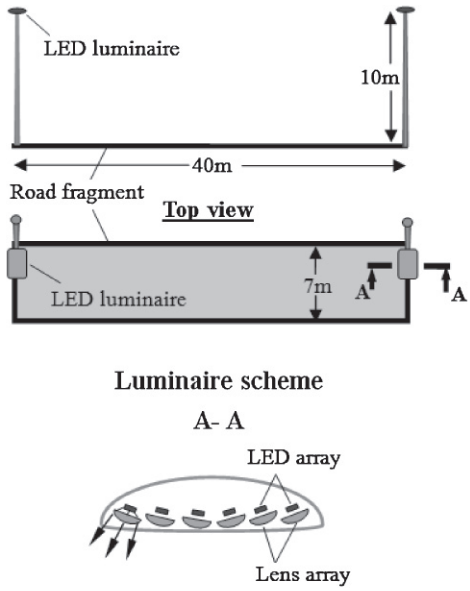


Fig. 9. Scheme of outdoor illumination system.

minimal value of illumination in two times less than required one. The design consisted of a number of successive approaches where different design parameters (shape of elements of the raster structure, orientation of LEDs and raster elements, shape of LED reflectors) are tested. Finally the required level of luminance was reached and the initial and final designed variants are shown in Fig. 10. Note that the initial variant of the luminary has no lens raster at all. We can see that the after the design goal was reached and minimal value of illuminance was 12.5 lx.

6. Conclusions

As demonstrated the algorithm is effective for backlight system design. The results are present for 3 kinds of backlight devices: the speedometer backlight and backlights for indoor and outdoor illuminations. Really the elaborated software can be used for any backlight design, in particular for various kinds of LCD.

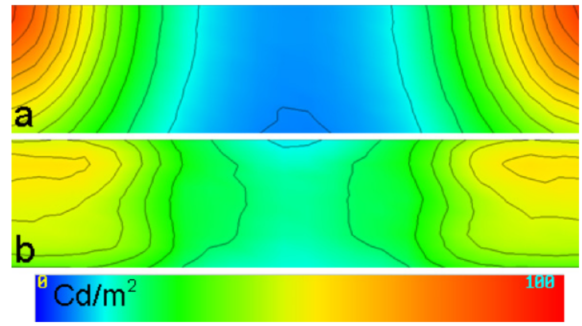


Fig. 10. (Color online) Outdoor luminaire: (a) initial road illumination; (b) designed road illumination.

Numerous simulations were performed for different systems, and following conclusions were made:

- Algorithm is effective for different backlight systems with various complexities;
- In most cases system can be optimized during 10–20 design steps. It requires several hours of computational time.

Autodesign program module is integrated with SPECTER optical simulation software.

Acknowledgment

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