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Optimization Design for the Dot Pattern of Led Light Guide Plate Using Soft Computing

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Abstract: The dot pattern distribution under the light guide plate is the major factor to influence the issues of uniformity and luminance. Thus, the key to affect the efficiency of the backlight module is the dot pattern design. This study presents a simulation experiment by using the optical simulation software of TracePro and the orthogonal array based on the Taguchi method. It then creates a dot pattern optical quality predictor by back-propagation neural network to find out the relationship between the radius sets of the dot pattern and the amount of output light in each area of the light guide plate. This dot pattern optical quality predictor can precisely predict the uniformity of the laminate derived from different radii in each dot pattern area. This experiment finally integrates the genetic algorithm method into the optical quality predictor to figure out full optimization for the dot pattern radius sets. The results of simulation test show that optimization design can reach the uniformity up to 90.19% calculated by 140-dot measuring, which can not only improve the uniformity of luminance in the incidence plane but can also simplify design of dot pattern distribution. This study will demonstrate that it can increase the speed and stability of the LGP microstructure design. The obtained uniformity and luminance can meet the standard in microstructure size. It can also reduce the reworking frequency and cost.

Key words: Backlight module, LGP, taguchi method, BPNN, GA

INTRODUCTION

The purpose of the dot pattern design under the LGP is based on its emission feature to change the light incident from the Point-light Source (LED) or the Linear Light Source (CCFL) to panel-light source with high uniformity. Three methods are employed in the experiment: 1) fixed radius of dot pattern with different intervals, 2) fixed interval with different radii of dot pattern and 3) different radii with different intervals. Sun *et al.* (2008) used the optical engine of the LCD and the backlight module to measure and analyze the LED light source. They computed the expected luminance and uniformity of the direct-light-type backlight module according to the concept of the luminosity. Besides, they fabricated a 42-inch LCD TV with RGB LED light source by controlling the luminance of the backlight module to explore and analyze the outcomes (Sun *et al.*, 2008). Li *et al.* (2012) divided the LGP into 6 parallel areas and adjusted the radii of the dot patterns for those areas where the luminance was lower than the objective value by interpolation. They optimized one dimension design for the dot pattern on the LGP by using curve fitting. Wang and Luo (2009) undertook an optical design to optimize the LGP in L-type light source based on CCFL. TracePro simulation software was used in their study according to the luminosity concept for calculating the expected luminance and uniformity of the LGP. The results showed the average lamination was 91.25%.

As for the research about the fixed interval with different radii of dot pattern, Fang *et al.* (2008) utilized split-region design that divided the LGP into plural regions with the same radius of dot pattern in each region. The study, based on the optimal iteration, employed the equivalent illumination in these regions to adjust the radius of the dot pattern until the luminance was evenly distributed. Chen *et al.* (2010) used CCFL as the light source to conduct a LGP design by using one-dimension optimization. They divided the LGP into 13 parallel regions by the data from the Taguchi method. Then, constructed the optical quality predictor that was the trapezoid dot pattern parameters on the LGP by using ANN and searched the optimal parameters by manipulating real-number GA. A LGP based on the CCFL light source was then developed by controlling the radius of the dot pattern under one-dimension. Furthermore, Kim *et al.* (2011) carried out a research in one-dimension optimization for the LED LGP. In this study, LEDs are set for the light source to obtain the optimal parameter of the dot pattern on LGP by using the Taguchi method, BPNN and GA.

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MATERIALS AND METHODS

This study delimits regions for the dot pattern under the LGP with fixed interval to optimize the design. The experimental employs a co mmercial simulation software package called TracePro to design and analyze a 2.5-inch backlight module. The backlight module comprises a LGP, three light-emitting diodes, a light case, a reflector and a frame. The LGP is a 54×42×1 mm sized panel as shown in Fig. 1. The material of the LGP is made of P mmA (refractive index: 1.4935). The light sources are three 3-lumen SMD-type LEDs with sizes of 3×1×1 mm placed at the short side of the LGP. The interval between the light source and the LGP is 0.6 mm. They are even-distanced arranged and the half-intensity light angle is 120° distributed by Lambertian light type. The refractive index of the light case and the reflector is 0.95 and the quantity of the simulation light beams is 6×10^5.

Parameter design and factor selection: It is very important to choose the radius value for the LGP in the early part of experiment. It will make the design difficult once the radius is set either too large or too small. Thus, the interval of the dot pattern is set to be 0.2 mm (the follow up experiment also uses this setting). Different radii are used to observe the luminance distribution. For example, Fig. 2 shows that when the radius is 0.2 mm and 0.3 mm, the luminance is smoother and it is easier to improve for the further study so it can be a guide for factor level selection.

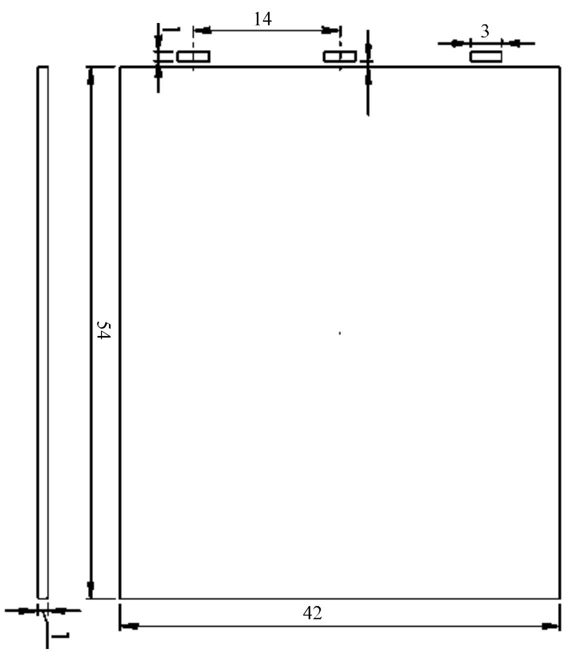

Fig. 1: Backlight module size

Once the radius value is given, the region on the LGP can be well delimited. By using this method, more identified regions are better for the test. On the contrary, it is difficult to satisfy the uniformity of the luminance on the light incidence with larger region for dot pattern design. Hence, according to the LED lighting feature, V-cut effects and the principle of light energy decreased in long distance, the LGP is divided into 31 regions with relative number, as illustrated in Fig. 3. Each region right in the front of the LEDs is not included for the design since the illumination over there is concentrated, dot pattern is tiny and the manufacturing is impeded. Because the luminance is higher if the radius of dot pattern is larger, the range for the radius is set as shown in Table 1.

Measurement of quality characteristics experiment: In this orthogonal array test, uniformity of LGP is set for the quality characteristics. In general, calculation for uniformity adopts 9-point measurement in which both the lighting area and sample number are not enough. It would cause error easily to mislead prediction on ANN. For this reason, the main lighting region of LGP is divided into 14-10 small areas as the dotted lines shown in Fig. 4 for measurement. The Irradiance Map resulted from the TracePro simulation is saved for Excel data. The luminance value is captured based on the 140 regions by macro function. The uniformity is computed to increase the accuracy.

Design of taguchi experiment: Twelve factors are included in this experiment that means there are

Table1: Range value for radius of dot pattern (Unit: mm)

Factor	Range value	Factor	Range value
1	0.0175~0.0225	7	0.0325~0.0375
2	0.0275~0.0325	8	0.0350~0.0400
3	0.0325~0.0375	9	0.0400~0.0450
4	0.0275~0.0325	10	0.0425~0.0475
5	0.0325~0.0375	11	0.0525~0.0575
6	0.0275~0.0325	12	0.0525~0.0575

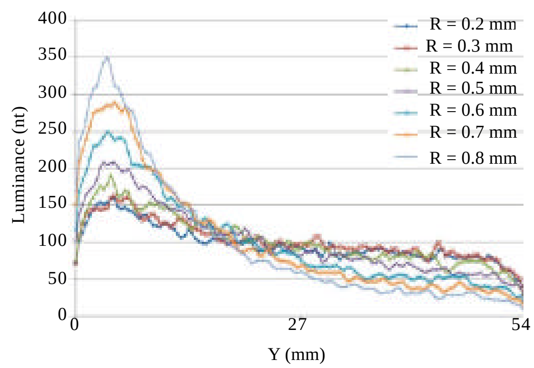

Fig. 2: Luminance distribution under different radius

Table 2: Factors and levels for Taguchi experiment (unit: mm)

	Factor											
Level	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0175	0.0275	0.0325	0.0275	0.0325	0.0275	0.0325	0.0350	0.0400	0.0425	0.0525	0.0525
2	0.0200	0.0300	0.0350	0.0300	0.0350	0.0300	0.0350	0.0375	0.0425	0.0450	0.0550	0.0550
3	0.0225	0.0325	0.0375	0.0325	0.0375	0.0325	0.0375	0.0400	0.0450	0.0475	0.0575	0.0575

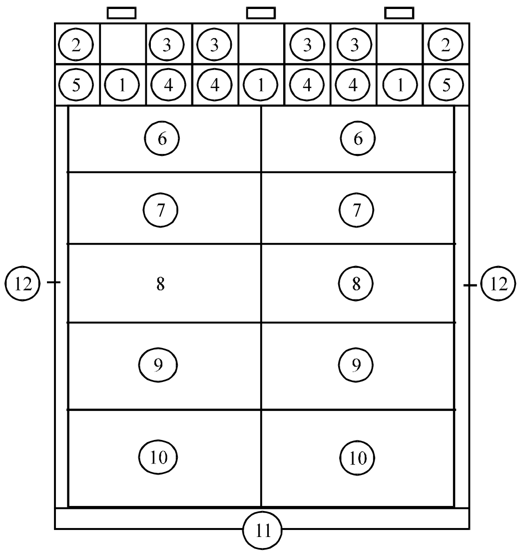

Fig. 3: Regions divided for dot pattern design

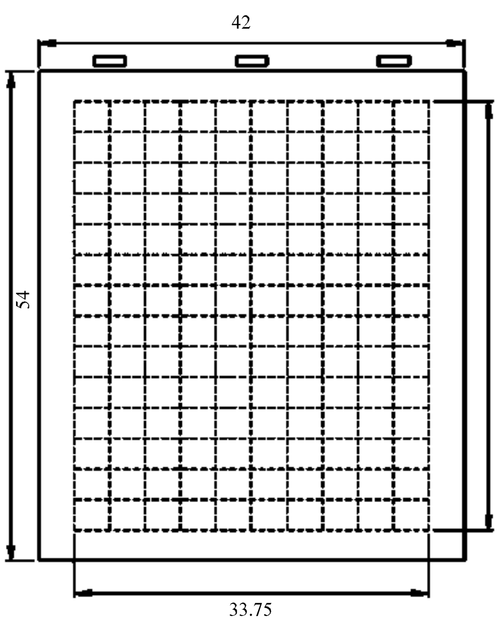

Fig. 4: 140 regions for measurement

12 different radius values of dot pattern in the regions. Since different radii in each region can affect the luminance distribution of the LGP. A mixed orthogonal rray of L_{27} (3^{13}) is employed. The factors and levels are shown in Table 2. Then, it applies every single parameter to the orthogonal array. 27 testing models are created to find out the luminance distribution of the LGP by using the optical simulation software, TracePro. After the 140 regions are measured, the obtained results are shown in Table 3.

Table 3: Results of the Taguchi experiment

	140 regions		
Experimental No.	L_{min} (nt)	L_{max} (nt)	Uniformity (%)
1	5716.23	7219.86	79.17
2	5727.48	7019.42	81.59
3	5714.33	7290.07	78.39
4	5783.91	7205.23	80.27
5	5961.43	7320.54	81.43
6	5796.68	7286.03	79.56
7	5657.70	7322.99	77.26
8	5934.91	7119.85	83.36
9	5831.38	7312.96	79.74
10	5899.09	7154.56	82.45
11	5705.45	7304.66	78.11
12	5848.70	7238.79	80.80
13	5620.69	7282.53	77.18
14	5926.52	7103.66	83.43
15	5804.25	7284.05	79.68
16	5787.24	7592.41	76.22
17	5684.43	7363.21	77.20
18	5787.28	7312.34	79.14
19	5867.22	7154.76	82.00
20	5915.10	7496.65	78.90
21	5773.47	7223.70	79.92
22	5956.41	7171.95	83.05
23	5508.94	7452.63	73.92
24	5814.91	7372.14	78.88
25	5617.79	7258.29	77.40
26	5759.96	7101.81	81.11
27	6044.26	6981.00	86.58

The results of the Taguchi point out that the experimental number 27 is the best setting for the dot pattern in which the uniformity is 86.58%. The optimal setting for the dot pattern radius is shown in Table 4 and the luminance distribution is illustrated in Fig. 5.

Parameter optimization for dot pattern

Constructing an optical quality predictor in BPNN: The data obtained from the orthogonal array tests are utilized for the BPNN training with 12 factors set for the input and the uniformity thereof set for the output. In order to avoid overtraining in BPNN, 5 test data randomly-added are applied to verify the prediction function, as listed in Table 5.

Table 4: Optimal parameter setting for the uniformity in the Taguchi experiment (unit: mm)

	Factor											
Level	1	2	3	4	5	6	7	8	9	10	11	12
Radius	0.0225	0.0325	0.035	0.0275	0.0375	0.03	0.0325	0.0375	0.04	0.0475	0.0525	0.0575

Table 5: Test data in BPNN (unit: mm)

	Factor												
No.	1	2	3	4	5	6	7	8	9	10	11	12	Uniformity (%)
1	0.02	0.0275	0.0325	0.0275	0.0325	0.03	0.0325	0.035	0.04	0.0425	0.0525	0.045	82.73
2	0.0225	0.03	0.035	0.03	0.0325	0.03	0.0325	0.0375	0.0425	0.0475	0.0525	0.0475	81.92
3	0.02	0.0325	0.0375	0.0325	0.035	0.03	0.0325	0.035	0.04	0.0425	0.0575	0.0425	81.96
4	0.02	0.0325	0.035	0.03	0.035	0.0325	0.035	0.0375	0.04	0.0425	0.045	0.0425	77.67
5	0.0225	0.0275	0.0375	0.03	0.035	0.0315	0.033	0.035	0.0375	0.04	0.045	0.04	77.19

Table 6: Parameter searching range for GA (unit: mm)

	Factor											
Searching range	1	2	3	4	5	6	7	8	9	10	11	12
UL	0.025	0.035	0.0375	0.030	0.040	0.0325	0.035	0.040	0.0425	0.050	0.055	0.060
LL	0.020	0.030	0.0325	0.025	0.035	0.0275	0.030	0.035	0.0375	0.045	0.050	0.055

Table 7: Radius of dot pattern optimization (unit: mm)

	Factor											
Searching range	1	2	3	4	5	6	7	8	9	10	11	12
Radius	0.0231	0.0321	0.034	0.0273	0.0377	0.0305	0.0323	0.0374	0.0412	0.0451	0.0513	0.0574

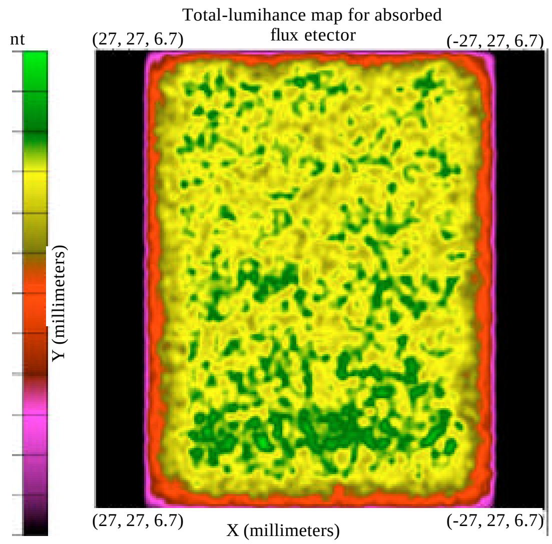

Fig. 5: Luminance distribution of the optimal uniformity in the Taguchi experiment

After 7151 generations of training via BPNN, the RMSE vales in training and testing are 0.0099 and 0.0179, respectively. Therefore, the errors generated in the further experiment can be within an accepted range. The prediction applied to the uniformity on the LGP should be turned out well.

Integrating GA into BPNN: By using GA, the optimal settings of the uniformity obtained from the previous Taguchi methods plus and minus half the experimental levels thereof are set for the Upper Limit (UL) and Lower Limit (LL), as shown in Table 6. Besides, 100 and 0.8 are set for the mating pool and mating rate, respectively. As

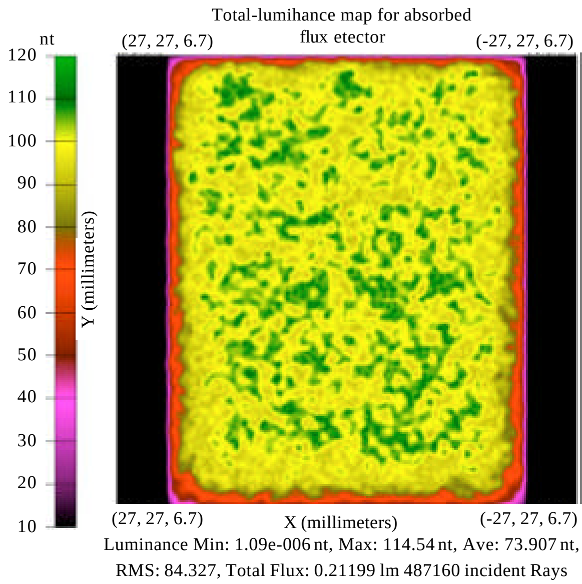

Fig. 6: Luminance distribution optimization on LGP

for the mutation procedure, a single point mutation method is adopted with mutation rate of 0.1. The convergence threshold is set to 10^{-6} or 10^{4} generations. Since, the quality goal is the uniformity of those 140 regions on the LGP, it is expected to be larger. For this reason, the fitness function is defined as follows:

$$\text{Min F (X)} = (1\text{-}U_N)^2 \qquad (1)$$

$$LL_i \le x_i \le UL_i \; i = 1, 2, 3... 12$$

where, U_N is the predictive value of the BPNN uniformity and X = [x_1, x_2, x_3?, x_{12}] is the radius parameters of the dot pattern. After the algorithm having integrated GA with the uniformity predictor, the optimal parameters for the radii of dot pattern are derived, as shown in Table 7. Moreover, the luminance distribution shown in Fig. 6 is gained after TracePro simulation and the uniformity of the 140 regions is 90.19%.

RESULTS AND DISCUSSION

According to the Taguchi method, it shows that the demarcation region proposed by this study is feasible. Incident regions are divided in the LED light source side of the LGP. After the light source goes through these regions, the curve of the luminance on the X-axis tends towards linear and the luminance distribution on the Y-axis slowly decreases. Therefore, the design can be carried out with a larger divided area. The LGP developed by 140 regions can result in uniformity of 90.19%. It is ascribed to the experimental data created by the Taguchi method, the optical quality predictor of the LGP structured by BPNN and the optimal combination of the dot patterns searched by GA. As compared with the optimal solution in the Taguchi method, 3.61% enhancement has been achieved. Besides, the uniformity of 93.16% has also been obtained by using the well-known 9-point measurement. These findings show the standard of the 140-region experiment proposed in this study is more rigorous and more conscientious for research.

CONCLUSION

The optimal process parameters for the dot pattern design under the LGP are presented. Based on the demarcation region developed by this study, the radii of dot pattern at different regions are explored. The experimental results are listed as in the followings:

- By the way of demarcation region in the optimal research of the dot-pattern radius, the LGP with 140 regions is successfully worked out. 90.19% in uniformity has been achieved by using the Taguchi method, BPNN and GA
- Since there are enough samples in the 140-region measurement proposed by this study, the uniformity of the LGP can be accurately presented. Those problems which usually occurred in the 9-point measurement can be avoided

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