Design of Diffractive Optical Elements for Improving the Background Image through Transparent Displays by the Simulated Annealing Method

Chen-Ho Cho, Yong-Xuan Chen, and Hoang-Yan Lin

r08941007@g.ntu.edu.tw
Graduate Institute of Photonics and Optoelectronics, and Department of Electrical Engineering,
National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan
Keywords: Diffraction Optical Element (DOE), Simulated Annealing Method(SA), Background Image

ABSTRACT

When the image passes through the transparent display, it becomes diffracted and its image quality is reduced. In order to eliminate the diffraction, we have used the simulated annealing method to design the diffraction optical element for improving the image quality.

1 Introduction

The development of displays has evolved from the cathode ray tube (CRT), plasma display panel (PDP), thin film transistor liquid crystal display (TFT-LCD), to light emitting displays such as organic light emitting diode (OLED) and micro light-emitting diode (Micro-LED).

In addition to display materials, the research and development of transparent displays is also a future trend. The structure of transparent displays is composed of many small metal electrodes and lines to form a periodic structure. The main feature is to allow users to watch the display content and the scenes behind the display simultaneously. Its application areas such as art gallery windows, car dashboards and refrigerator touch panels are all potential application markets for transparent displays. Currently commercial available transparent displays, such as OLED transparent displays, have the advantages of high internal quantum efficiency, low power consumption, high brightness, high contrast, etc [1].

There are many algorithms for designing diffractive optics elements, such as Iterative Fourier Transform Algorithm (IFTA), Yang-Gu algorithm [2], Direct Binary Search (DBS) [3], and the Simulated Annealing method (SA) [4-6].

The IFTA algorithm has been used for the design of diffractive optical elements in previous study. However, the IFTA algorithm is easy to converge to the local minimum. Therefore, the research goal of this paper is to design a phase-only diffractive optical element (DOE) to improve the image quality after the transparent display by using the simulated annealing algorithm (SA).

2 Experiment

In this paper, the commercial mathematics software MATLAB R2020a version is mainly used, and this software is used to handle a large number of tasks such as mathematical calculations, data analysis, image analysis, and algorithm development.

The architecture diagram is shown in Fig. 1. First, the image should be input to the program. When the image passes through the transparent display (that is, the grating in the Fig. 1), diffraction phenomenon will occur. The diffracted image is called the image after grating, and then passes through the DOE. We hope to reduce the diffraction caused by grating through the designed DOE to improve the quality of the background image.

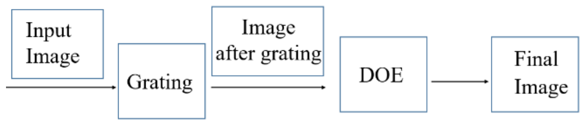

Fig. 1 Experimental architecture diagram.

Before executing the simulated annealing method, we need to define the cost function, which is given by

$$\mathrm{C} = (-200) \times \log(\mathrm{EFF}) + (-5) \times \log(\mathrm{PSNR}) + 2.7 \times 10^3 \times \mathrm{MSE} \qquad (1)$$

where the diffraction efficiency (EFF) is defined as the intensity ratio of the signal area to the entire area on the output field, the peak-signal-to-noise ratio (PSNR) is defined as the intensity ratio of the maxima of signal area to the minimum of noise area on the output field, and the mean-square-root (MSE) is defined as the mean value of the square of the difference between the intensity value of the target and the intensity value of output field.

Fig. 2 is the flow chart of the simulated annealing algorithm. First, the input image, the initial and the freezing temperatures, and the conditions of arrival stable state are given. Next, create a random phase distribution (U_1) from 0 to 2π and compute the cost function of the image after the phase distribution (U_1), that is C_1. And then, apply the perturbation of the initial phase distribution (U_1) to get U_2. Similarly, the cost function of the image after the phase distribution (U_2) is computed, that is C_2. The cost function difference $\Delta\mathrm{C}$ is defined as (C_2-C_1). If $\Delta\mathrm{C} \leq 0$ or $\Delta\mathrm{C} \geq 0$ with the probability $\mathrm{P} = \exp(-\Delta\mathrm{C}/\mathrm{T})$ larger than the random value P_a which is normally distributed in [0,1] generated by a computer, U_1 is replaced by U_2. If not, U_1 remains unchanged. When the process reaches a steady state, it is judged whether it has reached the freezing temperature. If it has not reached the freezing point temperature, the temperature will be cooled by the set cooling method, and the above process will be repeated until the freezing point temperature is reached, and the final output result will be obtained.

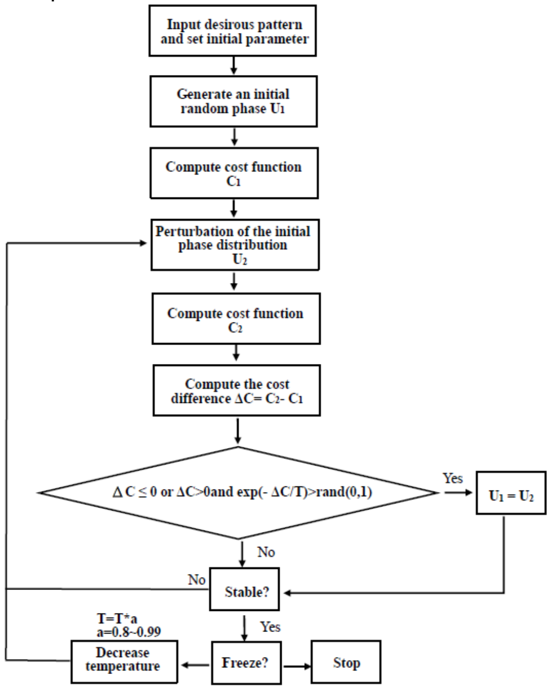

Fig. 2 A flow chart of the simulated annealing algorithm.

3 Discussion

We discussed the effects of different steady states, initial temperature, final temperature and cooling rate, and found that the initial temperature of $T_i = 100$, the freezing temperature of $T_f = 0.001$, the number of loops to steady state is set to be 200000 and the cooling rate is set to be 0.99, the output image performance is the best, as shown in Fig. 3(c).

Fig. 3(a) shows the input image containing 64x64 pixels, and Fig. 3(b) is the image after grating, and Fig. 3(c) is the image after the continuous phase DOE. We calculate the parameters of the image, the EFF of the image after the grating is 0.6236, the MSE is 0.0188, and the PSNR is 4.0500; then the image through the continuous phase DOE we designed, the EFF is 0.9246, the MSE is 0.0013, and the PSNR is 28.4119. We can find that the EFF and PSNR are increased and the MSE is decreased. Due to the difficulty of the manufacturing process, it is not easy to realize continuous phase diffractive optical elements in current technology, so we have to make a quantitative design for the diffractive optical elements. Fig. 3(d) and (e) are the images after the diffractive optical elements with 16-level quantization and 8-level quantization, respectively. Similarly, we also calculate the parameters of the two images. The EFF of the image through the 16-level phase DOE is 0.9151, the MSE is 0.0018, and the PSNR is 13.4023; then the image through the 8-level phase DOE, the EFF is 0.8850, the MSE is 0.0032, and the PSNR is 5.9845. According to the simulation results, the more levels of the DOE, the better the image quality of the output.

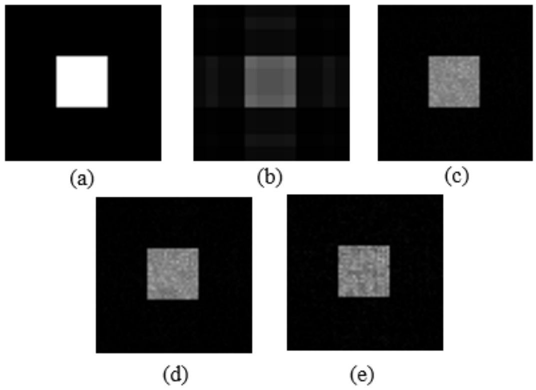

Fig. 3 (a)The input image; (b) the image after grating; (c) the image after the continuous phase DOE; (d) the image after the 16-level phase DOE; (e) the image after the 8-level phase DOE.

The background images are optimized by using the IFTA and SA algorithm and the results are compared. The former is a local search algorithm and the latter is a global search algorithm.

The parameters of the output image of using IFTA and SA are shown in Table 1. We can observe from Table 1 that the diffractive optical elements designed by the two algorithms, IFTA and SA, have the effect of optimizing image qualities. Although the EFF of SA is 0.0174 lower than that of IFTA, PSNR and MSE are both better than IFTA. Moreover, the image uniformity is also better, as shown in Fig. 4(b).

Table 1 The parameters of the output images by using IFTA and SA.

	EFF	Cost function	MSE	PSNR
IFTA	0.9420	14.89301	0.0043	5.6744
SA	0.9246	2.4460	0.0013	28.4119

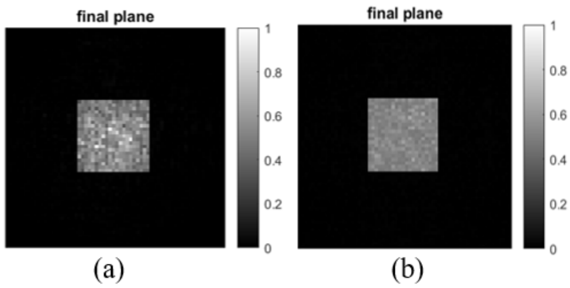

Fig. 4 (a) The output image of using IFTA; (b) the output image of using SA.

4 Conclusions

The simulated annealing method is used to design the phase-only diffraction optical element to improve the quality of the background image and reduce the diffraction caused by grating. In order to increase the diffraction efficiency of the background image, we should set a low freezing temperature and a large steady state.

The output image quality after the designed continuous phase diffractive optical element, and its MSE and cost function are all decreased. Also, both EFF and PSNR are increased, indicating that the output image quality has a trend of improvement.

Acknowledgement

The authors acknowledge financial support from Ministry of Science and Technology, Taiwan (MOST 109-2221-E-002-192-MY2 and 110-2218-E-011-009-MBK).

References

[1] V. Mann and V. Rastogi, "Dielectric nanoparticles for the enhancement of OLED light extraction efficiency," Optics Communications, vol. 387, pp. 202-207, (2017).

[2] G.-z. Yang, B.-z. Dong, B.-y. Gu, J.-y. Zhuang, and O. K. Ersoy, "Gerchberg–Saxton and Yang–Gu algorithms for phase retrieval in a nonunitary transform system: a comparison," Applied optics, vol. 33, no. 2, pp. 209-218, (1994).

[3] M. A. Seldowitz, J. P. Allebach, and D. W. Sweeney, "Synthesis of digital holograms by direct binary search," Applied optics, vol. 26, no. 14, pp. 2788-2798, (1987).

[4] S.Kirkpatrick, C. D. Gelatt, and M. P. Vecchi, "Optimization by simulated annealing," science, vol. 220, no. 4598, pp. 671-680, (1983).

[5] M. S. Kim and C. C. Guest, "Simulated annealing algorithm for binary phase only filters in pattern classification," Applied optics, vol. 29, no. 8, pp. 1203-1208, (1990).

[6] N. Yoshikawa and T. Yatagai, "Phase optimization of a kinoform by simulated annealing," Applied optics, vol. 33, no. 5, pp. 863-868, (1994).