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Efficient design of Fabry–Pérot cavity based transmissive structural color filters *via* machine learning

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Abstract

Structural color with high-resolution, high-saturation, and low-loss holds great promise in image display, data storage and information security. However, the design of structural color remains an open challenge. Here we use evolutionary algorithm to achieve a fast and accurate design of the Fabry-Pérot (F-P) cavity resonance based structural color filter. The excellent design performance is proved by the small color differences between the designed and targeted colors.

1. Introduction

Structural color can display high resolution color based on resonant between light and nanostructures [1]. Among different structural color techniques, Fabry-Pérot (F-P) cavity resonance based structural color filter enjoys unique advantages of angular insensitivity, low cost, easy fabrication and great scalability, is a promising technology for different applications such as color decoration and printing, optical encryption and display devices [2]. One challenge for structural color is the inverse design of the structure to realize the desired color. The conventional design strategy relies on full electromagnetic simulations in which the resonance spectrum and desired properties are optimized by parameter sweepings to identify the most suitable geometries. This could be prohibitive difficult when the multiple parameters are optimized simultaneously.

Evolutionary algorithm (EA) is one type of the derivative-free optimization method which is an appealing option for solving this optimization problem. It uses stochastic and direct-search methods to find good approximate solutions to complex problems with little to no prior knowledge of the optimization problem [3]. Here we propose a method for designing F-P-cavity-based color filters using evolutionary algorithm. The excellent designing performance represented by the color differences (ΔE) between design and desired colors will be presented.

2. General Instructions

The schematic of the F-P cavity based transmissive filter is illustrates in Fig. 1a. It consists of one dielectric layer (SiO_2) which is sandwiched between two metal layers (Ag). A range of light can be selectively reflected or transmitted due to the constructive or destructive interference determined by the thickness of these layers. By varying the thickness of the Ag and SiO_2 layers within 0-50 nm and 0-1000 nm respectively, a large color gamut can be achieved, demonstrated as the black dots in the Chromaticity coordinates in Fig. 1b.

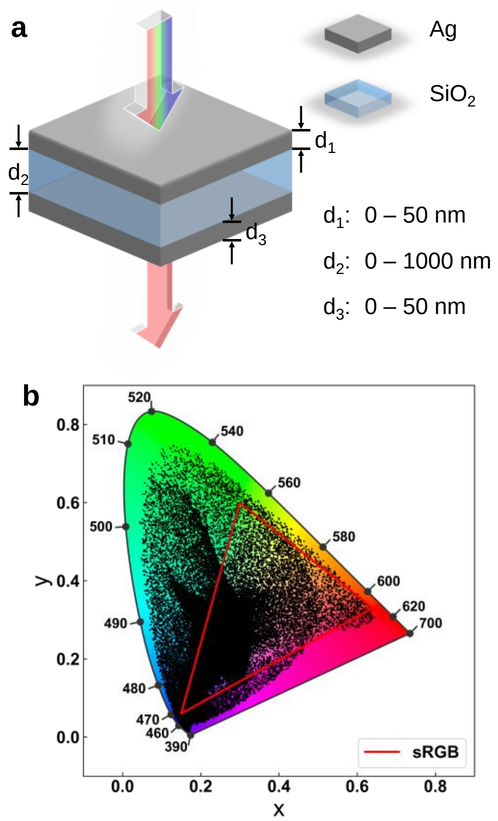

Fig. 1 (a) Schematic of F-P-cavity-based color filters. (b) The CIE 1931 XYZ chromaticity diagram obtained by proposed color filters.

The flowchart of the EA process in this work is shown in Fig.2. It is a refined iterative process in which an elite percentage of the parameter sets (d_1, d_2 and d_3) are retained through each iteration, allowing the samples to genetically evolve until the best option has been identified. A population size (i.e. candidate structures) of 100 is defined. Within each generation, 100 structures were firstly calculated to obtain 100 colors. These colors were compared with the targeted colors to obtain corresponding ΔEs while the structure with smallest ΔE was selected into the next generation. Another 100 candidate structures were subsequently generated based on the best solution obtained in the previous generation with certain mutations. In this way, the process is evolved gradually toward better solutions.

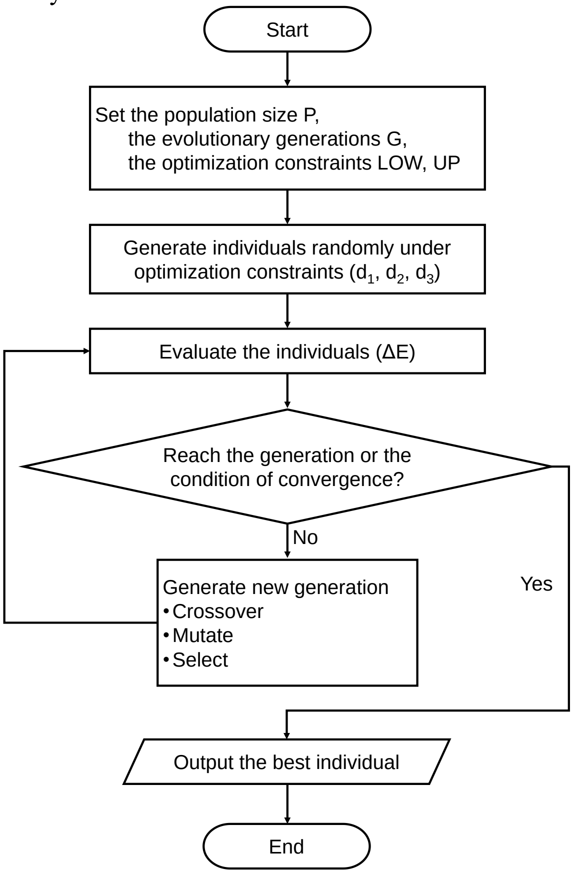

Fig. 2 The flowchart of the EA process.

Fig.3 displays the evolution of average and minimum ΔEs with generation for one target color design. It is clear that both ΔE decrease drastically indicating a good converge of the process. The minimum ΔE achieved is at 0.68 which is classified as undistinguishable by human eyes.

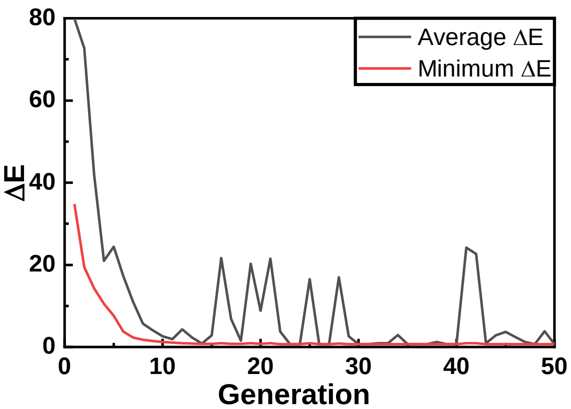

Fig. 3 The average and minimum ΔEs as a function of generation.

Table 1 lists 6 representative colors that were designed by this EA process. All designed colors are very similar to their targets average ΔE of 2.5 obtained. This is competitive with most of the commercial display products. The good performance of this process is further proved by designing the structures to display the painting of *Bend in the Epte River Near Giverny* by Claude Monet (500×395 color pixels, shown in Fig. 4a). The results can directly output the designed geometric parameters for all the pixels and the generated painting colors are shown in Fig. 4b. Very good similarity between the two pictures suggests the high design accuracy of our process.

Table 1. Comparison of 6 designed structural color with their targets.

Target Color	Target sRGB	Design Color	Design (nm)	Design sRGB	ΔE
	180-0-0		31-160-33	163-47-27	4.83
	0-180-0		26-134-30	50-177-50	3.12
	0-0-180		24-97-40	23-2-177	0.68
	0-180-180		10-663-19	30-179-178	0.74
	180-0-180		19-379-21	173-26-178	1.20
	180-180-0		22-139-26	177-176-66	4.78

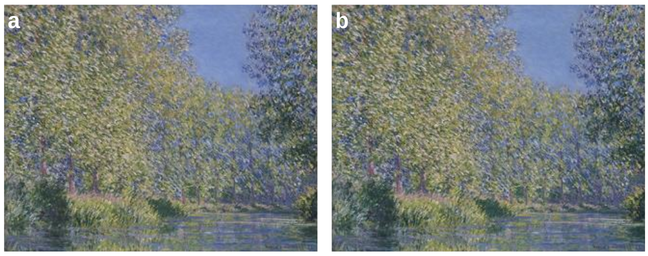

Fig. 4 (a) The desired colors of the painting *Bend in the Epte River near Giverny* by Claude Monet, and (b) the designed color by the EA process. The painting is reproduced with permission of the Philadelphia Museum of Art, The William L. Elkins Collection, 1924, E1924-3-16.

3. Conclusions

This work reports the F-P cavity color filter design using evolutionary algorithm. An excellent designing accuracy has been obtained as proved by the high similarities between the designed and targeted color. This good performance projects a promising prospect for the application of evolutionary algorithm in structural color design.

References

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