

Self-Adaptive Niching Differential Evolution and Its Application to Semi-Fragile Watermarking for Two-Dimensional Barcodes on Mobile Phone Screen

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ABSTRACT

This paper proposes an algorithm named Neighborhood-and-Crowding-based Self-Adaptive Differential Evolution (NCjDE) for multi-optima problems. This paper also proposes its application for semi-fragile watermarking of colored two-dimensional (2D) barcodes with adequate semi-fragileness for copy detection, which are displayed on mobile phone screen and used for quick verification of items such as airplane boarding passes and coupons.

Categories and Subject Descriptors

G.1.6 [Mathematics of Computing]: Optimization—*Global optimization*; I.5.4 [Computing Methodologies]: Pattern Recognition—*Signal processing*

Keywords

differential evolution, control parameter adjustment, niching, watermarking, two-dimensional barcode, copy detection

1. INTRODUCTION

Evolutionary algorithms (EAs) have been applied to numerous real-world problems. Some problems are multimodal; that is, they contain more than one highly qualified optimal and quasi-optimal solution that should be found by optimization. Finding those solutions can become more important than relying on a single optimal solution, because with multiple solutions in hand, it becomes possible to choose the most suitable solution from those other solutions.

One drawback of employing EAs to solve real-world problems is that it can, in many cases, be difficult to find experimentally an appropriate configuration of EA control parameters owing to time and computational resource limitations.

This paper proposes an algorithm, named Neighborhood-and-Crowding-based Self-Adaptive Differential Evolution (NCjDE), for multimodal optimization without the need to adjust control parameters. This algorithm is designed by combining Neighborhood-based Crowding Differential Evolution (NCDE) [3] and Self-Adaptive Differential Evolution

(jDE) [1]. Combining NCDE with jDE does not result in interference between the two algorithms, and thus NCjDE successfully inherits the advantages of both NCDE and jDE. Compared to other niching algorithms, the advantage of NCjDE is free from control parameter adjustment.

This paper also focuses on the problem of semi-fragile watermarking for two-dimensional (2D) color barcodes in which the appropriate barcode colors and watermark are unknown. Over the last two or three years, paperless verification through the use of 2D barcodes as passes and tickets has become increasingly common. With mobile phone apps, the barcode is displayed on the phone display and the passenger holds his/her mobile phone over a barcode reader. However, it is difficult to prevent or detect illegal replication taking with another mobile phones camera.

This paper also proposes a method for semi-fragile watermarking of colored 2D barcodes displayed on mobile phones by applying the proposed NCjDE. The proposed method optimizes 2D color and watermarking parameters, enabling to distinguish invalid copies from original 2D barcodes. To enhance the design flexibility of colored 2D codes, it is important to find more than one promising set of color and watermarking parameters.

2. THE PROPOSED METHOD

The problem of generating semi-fragile watermark [2] comprises eight design variables. Color components of positive modules are variables for coloring a 2D barcode. The remaining five variables are for watermarking: dynamic range reduce levels DR_L and DR_H , watermark strength L_p and L_n , and watermark resolution. The watermark resolution determines the module size of 2D code (watermark image) that is different from the base 2D code (host image). These parameters determine the robustness of the watermark, and should be varied depending on the color of the base 2D code.

To optimize colored 2D codes with semi-fragile watermark for mobile phones, this paper produces a system for semi-fragile watermark evaluation as shown in Fig. 2. Three phones and two cameras for each mobile phone model are used for evaluation of watermarks extracted from both valid and illegally replicated barcodes.

The objective function of this problem is the difference of watermark detection rates WDR between watermarks from

a valid 2D code and a replicated one. WDR is the ratio of pixels which have the same value between original and extracted images of binarized watermarks.

Fitness $f(x)$ of individual x is calculated as follows:

$$f(x) = \frac{1}{N_M} \sum_{m=1}^{N_M} \{WDR(w_{valid}) - WDR(w_{replicated})\} \quad (1)$$

where N_M denotes the number of mobile phone models used, w_{valid} and $w_{replicated}$ are watermark images extracted from capture images of valid and replicated 2D barcodes.

Fig. 1 shows the proposed NCjDE algorithm. In the main loop, neighborhood based mutation is applied at first (steps 2 through 5). In selection step (step 7), the trial vector $u_{i,g}$ is compared with the most nearest individual in the decision variable space, whereas, in canonical DE, the trial vector $u_{i,g}$ is compared with the target vector $x_{i,g}$. Parameter update is performed after selection (step 8).

3. EVALUATION

The proposed semi-fragile watermarking method was evaluated. In this experiment, single smartphone model (display: 5.0 inch IPS 800×480 pixels resolution, camera: 5 megapixel resolution) was utilized. As a decoder's camera, USB-connected cameras (3 megapixel resolution) were utilized. Population size and Generation limit was set to 50 and 200, respectively.

Fig. 3 shows transitions of the best individual fitness, average fitness (except penalized individuals), and population diversity. The diversity is an average distance between all individuals in normalized design variable space in which all design variables ranges are normalized as $[0, 1]$. NCjDE successfully maintained the population diversity even in the late stage of the search, whereas in jDE individuals converged into certain area of the search space.

Fig. 4 shows example solutions found by NCjDE. Watermark pattern could be extracted only from the valid 2D code images because in the replicated images watermark was destroyed by strong horizontal patterns.

4. CONCLUSIONS

Proposed in this paper is a variant of DE, named NCjDE, and its application to semi-fragile watermark generation for copy detection. Experimental results showed that the proposed watermarking method could generate various colored 2D codes with semi-fragile watermark which allows distinguishing the valid and replicated 2D code.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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- Step 1 Initialize population by random.
- Step 2 For each individual i , do step 2 through 8.
- Step 3 Find the most similar m neighbors to i in decision variable space to form a subpopulation $sp_{i,g}$ (neighborhood mutation).
- Step 4 Pick a base vector $x_{b,g}$ and vectors $x_{r1,g}$ and $x_{r2,g}$ for a difference vector from $sp_{i,g}$.
- Step 5 Generate a mutant vector $v_{i,g}$ from the vectors selected in step 4.
- Step 6 Make a trial vector $u_{i,g}$ by mixing the $x_{i,g}$ and $v_{i,g}$ by crossover.
- Step 7 Find the most similar individual and replace it with $u_{i,g}$ if $u_{i,g}$ has better fitness value than the most similar one (crowding).
- Step 8 Randomly change scale factor and crossover rate with the probability of τ_1 and τ_2 respectively (self-adapting parameters).
- Step 9 Stop if a termination criterion is satisfied. Otherwise, go back to step 2.

Figure 1: The proposed NCjDE algorithm.

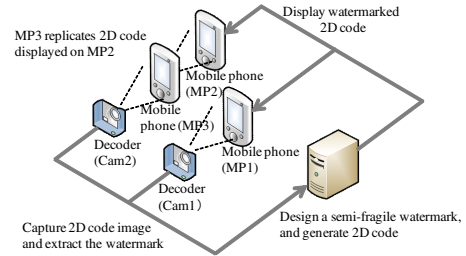


Figure 2: Watermarking evaluation system.

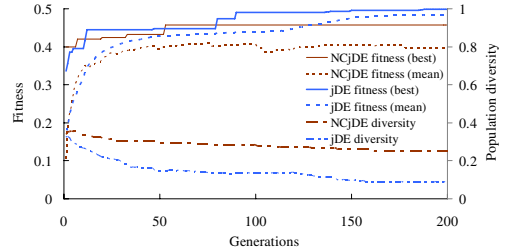


Figure 3: Transitions of fitness and diversity.

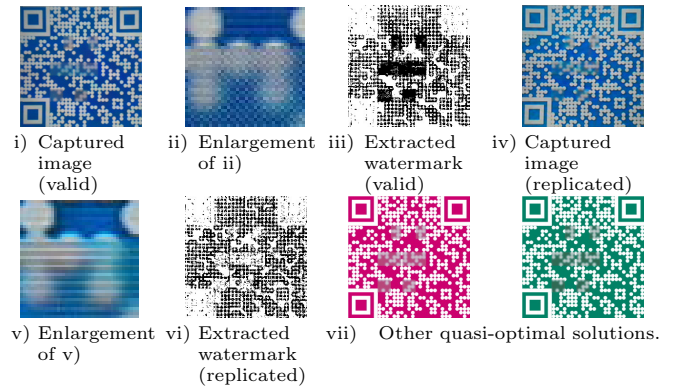


Figure 4: Generated color QR codes and extracted watermark images.

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