Semi-Fragile Watermark Design for Detecting Illegal Two-Dimensional Barcodes by Evolutionary Multi-objective Optimization

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ABSTRACT

This study proposes a semi-fragile watermark design method for detecting illegally copied 2D barcodes. The proposed method uses real mobile phones for fitness calculation rather than simulation. In addition, we formulate this task as a multi-objective optimization problem to design a commonly usable watermark on various mobile phones.

Categories and Subject Descriptors

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

Keywords

multi-objective optimization; semi-fragile watermarking; two-dimensional barcode; copy detection; discrete wavelet transformation

1. INTRODUCTION

Over the past few years, the use of 2D codes displayed on mobile phone screens has become increasingly common as a paperless verification in which passes and tickets are presented as 2D barcodes. In mobile phone apps such as "Mobile AMC Application" by All Nippon Airways and "Passbook" by Apple, the barcode is displayed on the phone screen and a passenger holds his/her mobile phone over a barcode reader. However, easy replication by mobile phone cameras is apprehended. Illegal replications by other mobile phone cameras are difficult to prevent and detect.

Ono et al. proposed a semi-fragile watermarking scheme for color 2D barcodes that detects illegal replication [3, 4]. Although this scheme produces copy-detectable and attractive 2D barcodes, it is designed for barcodes on print media. Validation techniques for barcodes displayed on mobile phone screens have not been researched, and whether the semi-fragile watermarking scheme by Ono et al. is effective for barcodes displayed on mobile phones is uncertain. In particular, the materials in the flat panel displays of mobile phones are highly variable and include twisted nematic (TN) liquid crystal displays (LCD), thin-film transistor (TFT) LCDs, and electroluminescent (EL) materials. Thus, designing a watermarking scheme that is accessible to various mobile phones is a challenging task.

To meet this challenge, we generate a semi-fragile watermark for 2D codes displayed on mobile phones by optimizing the watermarking scheme. Various types of flat display panels likely require different watermarking schemes. Thus, to obtain actual valid and counterfeit 2D code images, the solutions of the proposed method are evaluated on a range of real mobile phones. In addition, a flexible watermark that can be used on various mobile phones is achieved by formulating the semi-fragile watermarking design as a multi-objective optimization problem. Implementing multi-objective optimization with real mobile phones is an effective design approach for both semi-fragile as well as inconspicuous robust watermarks.

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2. THE PROPOSED METHOD

The proposed semi-fragile watermark scheme for 2D code displayed on mobile phone screens is based on the following watermark design approach:

First, the solution is evaluated on real mobile phones. The proposed method captures images of original and maliciously copied 2D codes from real mobile phones. To render the semi-fragile watermark available through a range of mobile phones, the proposed method accommodates mobile phone models with various flat panel displays such as LCDs (and their main variants, TN and TFT), and EL.

Second, the proposed method formulates the task as a multi-objective optimization problem. The semi-fragile watermark sought in this study is accessible to various mobile phones, and for this reason, the objective function should be the worst semi-fragileness score among the mobile phones. However, this function cannot improve a solution that is effective in a specific mobile phone with a little degrade in other mobile phones. The semi-fragile watermark in the proposed method is designed by a multi-objective approach. By allowing each objective function to represent the semi-fragileness of each mobile phone, slight improvement in a

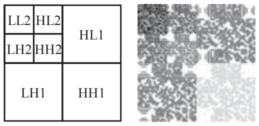

Figure 1: DWT subbands.

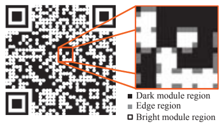

Figure 2: Three 2D code regions.

Figure 3: The implemented system.

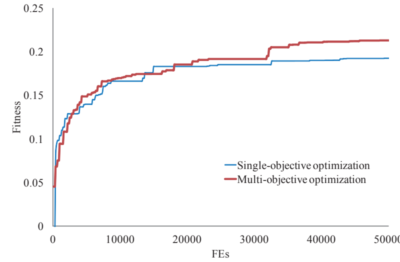

Figure 4: Comparison on the fitness transitions.

certain mobile phone enhances both the spread and convergence of the Pareto front.

In the proposed method, a cover image is decomposed by DWT, and a watermark is embedded to the selected subbands of the selected regions of the cover image. The strength levels of the watermark for each subband and region are determined according to the optimized scheme.

The watermark image is embedded to coefficients in the selected subbands with adjusted strength $L_{b,r}$, where b represents a subband, r represents a region. $L_{b,r}$ is calculated as follows:

$$L_{b,r} = \begin{cases} 2 \times (\alpha_{b,r} - 0.5) \times L_{max} & \text{if } \alpha_{b,r} > 0.5 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $\alpha_{b,r}$ is a design variable that simultaneously specifies the subband selection and strength. A subband with $\alpha_{b,r}$ below 0.5 is not related to watermark embedding.

This task requires 21 variables: seven subbands (HH1, HL1, LH1, HH2, HL2, LH2, and LL2) in three cover image regions of maximum, minimum and intermediate luminance intensities, as shown in Figs. 1 and 2.

The fitness $\boldsymbol{f}(I) = (f_1(I), f_2(I), \ldots, f_{N_m}(I))$ of individual I is a vector of objective functions $f_m(I)$, where N_m denotes the number of mobile phone models used. Objective function $f_m(I)$ for mobile phone m is calculated from the BCR as follows:

$$\begin{aligned} f_m(I) \quad = \quad & \mathrm{BCR}(W, W^{val,m}) - \mathrm{BCR}(W, W^{rep,m}) \\ & - P(Y^{val,m}) \end{aligned} \quad (2)$$

where $W^{val,m}$ and $W^{rep,m}$ are watermark images extracted from captured images of valid and replicated 2D barcodes, respectively, displayed on mobile phone m. BCR is the rate of the correctly extracted watermark bits. If error correction is performed when decoding the validimage of the cover 2D code $Y^{val,m}$, the penalty P is applied and the fitness declines proportionally to the usage rate of the error correction.

We implement an evaluation system for the scheme as shown in Fig. 3. Barcodes are evaluated with two phones and a camera for each mobile phone model, by sequentially switching the roles of the mobile phones to display valid and replicated 2D code images.

3. EVALUATION

The proposed method was evaluated with the implemented system involving three smart phone models. NSGA-II [2] was used for multi-objective optimization with blend crossover (BLX-α) and uniform mutation. Population size and the maximum number of function evaluations (FEs) were set to 300 and 50,000, respectively.

To clarify the effect of the multi-objective optimization, the proposed method with three objectives was compared to single-objective optimization (SOO) which has the worst value among mobile phone models. Self adaptive differential evolution [1] was used for single-objective optimization.

Fig. 4 shows the fitness transitions of the best solutions in the proposed method and the SOO based method averaged over three runs. Though the proposed method does not consider the worst value among the fitness functions, the proposed method found better solutions than the SOO based method.

4. CONCLUSIONS

This study proposes a semi-fragile watermark design method for a 2D code displayed on a mobile phone screen. Experimental results demonstrated that the multi-objective optimization model converges to better solution than the single-objective optimization model.

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