Watermark Embedding and Extraction Scheme Design by Two-stage Optimization for Illegal Replication Detection of Two-dimensional Barcodes

Satoshi Ono¹, Kentaro Nakai¹, Takeru Maehara¹ and Ryo Ikeda²

¹Department of Information Science and Biomedical Engineering, Graduate School of Science and Engineering, Kagoshima University, 1-21-40 Korimoto, Kagoshima 890-0065, Japan
²Technical Division, Graduate School of Science and Engineering, Kagoshima University, 1-21-40 Korimoto, Kagoshima 890-0065, Japan

Keywords: Watermark Optimization, Mobile Phone, Two-dimensional Barcode.

Abstract: Recently, two-dimensional (2D) barcodes displayed on mobile phones are becoming used for authentication such as airplane boarding pass and online payment. Digital watermarking is promising technology to detect illegal replication or fabrication of such 2D codes. However, due to geometric distortions and/or interferences between patterns of camera sensors and screen pixels, watermark may not be sufficiently extracted from sub-bands which are used when embedding the watermark. This paper proposes a two-stage optimization method for watermark embedding and extracting scheme design. The proposed method discriminates frequency sub-bands between for embedding and extraction, whereas general watermarking schemes extract the watermark from the same subbands as while embedding. To evaluate actual image deterioration by digital-analogue conversion with mobile phone screen and camera, the proposed method uses actual mobile phones to obtain real images of valid and replicated 2D codes. Experimental result have shown that the proposed two-stage optimization of watermark embedding and extracting schemes improved watermark performance for 2D code replication detection.

1 INTRODUCTION

Barcodes are used for object recognition and identification in various areas, such as production, logistics, and commerce. Quick Response (QR) codes, a kind of two-dimensional barcode (2D code) investigated by Denso Wave Inc., are currently used in Japan as a shorthand method of accessing (an “analogue shortcut”), for example a URL, an e-mail address, a phone number, and so on. Most Japanese mobile phones are equipped with a camera and QR code decoder. By holding a mobile phone over QR codes printed on papers, billboards, television screens, or digital signage monitors, users can decode the QR code and browse Web sites or send e-mails without typing URLs or e-mail addresses on their mobile phones.

In recent years, QR codes (and other 2D codes) are becoming used for authentication such as airplane boarding passes and online payments. In particular, over the past few years, 2D codes displayed on mobile phone screens have become increasingly common as a paperless verification. 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. Such paperless tickets and coupons promote reduction of environmental impacts. Indeed, in 2007, the International Air Transport Association standardized an automatic check-in system using a 2D code to reduce expenses and industrial waste by replacing boarding passes using magnetic tape with mobile phones.

However, illegal replication or fabrication of 2D codes has not been considered to date. Fig. 1 shows an example replication of a 2D code displayed on a mobile phone screen by other mobile phone’s camera. The importance of technologies for detecting counterfeit and copied 2D code is rising, not only to avoid financial losses but also to enhance the security and safety of social hubs such as airports and train stations. Although woven patterns are widely used in paper documents to detect a copy, it is difficult to distinguish between valid and counterfeit 2D codes displayed on mobile phone screens.
Recently, digital watermarking has been widely used for copyright protection and the detection of image modification and attacks. Digital watermarking techniques can be divided into robust and fragile watermarking. For instance, robust watermarking is used to protect copyright information even when a watermarked image is replicated or modified, while a fragile watermark detects modification and tampering attacks by being destroyed by them. Semi-fragile watermarking is used to detect modifications and attacks on printed images, whereas fragile watermarking is used to detect modifications and attacks by digital image processing. Compared to robust and fragile watermarking, little attention has been paid to semi-fragile watermarking (Rey and Dugelay, 2002; Song et al., 2001).

Ono et al. proposed a semi-fragile watermarking scheme for color 2D barcodes that detects illegal replication (Ono et al., 2011; Ono et al., 2013; Ono et al., 2014). This method uses Discrete Wavelet Transform (DWT) (Kundur and Hatzinakos, 1997; Kundur and Hatzinakos, 1998), and embeds a watermark image as a high-frequency component in the oblique direction. Fig. 2 shows frequency subbands and example output images of three-level DWT; HL, LH and HH denotes high frequency coefficients (subbands) in horizontal, vertical and diagonal directions, respectively, and LL is low image subbands. The digit of subband name corresponds to the DWT level.

Illegal replication of printed images with the above watermark by photocopiers destroys the watermark because the photocopiers express colors with dotted or diagonal striped patterns of primary colors, which involve diagonal high frequency component. Although the above semi-fragile watermarking method produces copy-detectable 2D barcodes, the method is basically designed for barcodes on print media.

Then, Ono et al. applied this scheme to 2D code displayed on mobile phone screens, which was achieved by subband selection and watermarking strength optimization (Ono et al., 2014). Various types of flat display panels likely require different watermarking schemes. Thus, to obtain actual valid and counterfeit 2D code images, the solutions of this method are evaluated on actual mobile phones. In addition, a flexible watermark that can be used on various mobile phones is achieved by formulating the watermark 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.

However, due to slight geometric distortions and frequency gaps between screen pixels and camera imaging sensors, watermark may not be sufficiently extracted from subbands which are used when embedding the watermark. Fig. 3 shows an example of watermark extraction from a camera-captured image. In this example, although the watermark is embedded into LH2, the watermark is extracted from LH1 in addition to LH2. The above-described shows that robust watermark extraction should be performed by referring some additional subbands. However, the pre-
vious method (Ono et al., 2014) embeds watermark into multiple subbands, e.g., HL1, HL2, and HH2 are used at darker regions of a cover image. Therefore, it is difficult to determine an appropriate subband set for extracting the watermark when it is embedded to multiple subbands.

This paper proposes a method for simultaneous optimization of watermark embedding and extracting schemes. The proposed method discriminates frequency subbands and strength between when embedding and extraction, whereas general watermarking schemes extract the watermark from the same subbands as while embedding. Although it is expected that simultaneous optimization for watermark embedding and extraction schemes allows to achieve appropriate semi-fragile watermarking, the optimization problem scale becomes larger. Therefore, the proposed method performs a two-stage optimization, in which watermarking subbands and strength are optimized first without distinction between during embedding and extracting, and then subbands and their strength peculiar to both embedding and extraction are discriminated and optimized simultaneously. To evaluate actual image deterioration by digital-analogue conversion with mobile phone screen and camera, the proposed method uses actual mobile phones to obtain valid and replicated 2D code images.

Experimental results have shown that the simultaneous optimization of watermark embedding and extracting schemes improved watermark performance for replication detection.

2 RELATED WORK

Many researchers of digital image copyright protection have adopted optimization techniques in their robust watermark designs. For example, Vahedi et al. proposed a watermarking approach for color images (Vahedi et al., 2012) using discrete wavelet transform (DWT) analysis (Kundur and Hatzinakos, 1997; Kundur and Hatzinakos, 1998). This method optimizes the watermark embed levels for subbands, thereby improving watermark robustness to various intentional and unintentional attacks while ensuring a high level of perceptual quality. The objective function is the linear sum of three objectives: visual quality, robustness, and amount of embedded information. Mingzhi and Yan (Mingzhi et al., 2013) proposed a combined DWT and Discrete Cosine Transform (DCT) scheme (Rao and Yip, 1990), based on a watermarking scheme optimized by genetic algorithm (GA) (Goldberg, 1989). In this method, fitness calculations are performed on images corrupted by attacks, such as JPEG compression, Gaussian filtering, image sharpening, and cropping. In the method of Chu et al., DWT is used to select appropriate zerotrees that preserve both the cover image quality and the robust embedded watermark (Chu et al., 2008). Huang et al. optimized both the watermarked image quality and the robustness of the extracted watermarks by tabu search (TS). This approach overcomes channel impairments while ensuring copyright and ownership protection (Huang et al., 2011). Another approach is singular value decomposition and lifting wavelet decomposition (Loukhaoukha et al., 2014). In this method, the subjective quality and wavelet analyses are performed by a just noticeable distortion (JND) model and Sym-4, respectively.

All the above methods attempt to resist deliberate attacks by applying benchmarks to watermarked digital media, and the solutions are evaluated by simulation.

3 THE PROPOSED METHOD

3.1 Overview

This paper proposes a design method for watermark embedding and extracting scheme in order to distinguish genuine 2D codes and their replica. The target 2D codes are displayed on mobile phone screens, and we assume that replication is performed by capturing the genuine 2D code displayed on a mobile phone with another mobile phone camera as shown in Fig. 1. Semi-fragile watermark is necessary to discriminate between them; the watermark is extracted only from genuine 2D codes, and the replication, which is digital-analogue conversion (Ho et al., 2003), destroys the watermark.

The basic idea of the proposed method is as follows:

1. The proposed method uses 3-level 2D Haar DWT based watermark.
2. Different frequency subband sets are allowed to be used during watermark embedding and extracting.
3. Real-coded GA (Eshelman and Schaffer, 1993) is used as an optimizer.
4. Two-stage optimization is adopted to find a good solution of the target high-dimension problem.
5. Actual mobile phones are used to evaluate semi-fragileness of designed watermark schemes.}

---

1 Digital copying of 2D code images can be prevented by other digital technologies.
The proposed method iterates solution candidates (individuals) generation and their evaluation according to general process flow of GA.

Unlike general non-linear programming algorithms, GA is a multi-point search method in which many individuals simultaneously look for a global optimum and interact with each other. The initial population of individuals is generated randomly, and population recombination is performed by genetic operators; selection, mutation and crossover.

The proposed method evaluates individuals with actual mobile phones. Fig. 5 shows the system for individual evaluation. A watermarked image, which is a phenotype of individual, is generated according to chromosome of the individual. The above watermarked image, which is regarded as a valid code, is displayed on mobile phone MP1 and captured by camera Cam1.

After capturing the valid 2D code image, the valid code is also displayed on MP2. Then, replication is performed; the above 2D code displayed on MP2 is captured by a camera of MP3. The replicated 2D code image is shown on MP3 screen, and it is captured by camera Cam2. To avoid the influence of image processing and compression of file format, MP3 directly shows the captured image without recording. The valid watermarking extraction process performed by MP1 and Cam1 evaluates the robustness of the watermark sufficiently to overcome the noise caused by digital-analogue conversions via the mobile phone screen and the camera. Moreover, the replication process by MP2, MP3, and Cam2 evaluates the fragility of the watermark sufficiently to be destroyed by two digital-analogue conversions between MP3 and MP2 and between MP2 and Cam2.

### 3.3 Optimization

#### 3.3.1 Design Variables

Simultaneous optimization of watermark embedding and extracting scheme that is a target task of the proposed method involves both frequency band selection and strength adjustment. Adequate subband selection and embedding/extracting strength adjustment are indispensable in semi-fragile watermarking. Therefore, design variables are designed to cope with both subband selection and strength adjustment. Variable $v_{p,b,r}$ is a real value and ranges from 0 to 1, where $p$ denotes the process, embedding or extracting, $b$ denotes a subband, and $r$ denotes cover 2D code region to be embedded. The subband set used in this study comprises vertical direction subbands LH1, LH2, LH3, horizontal direction subbands HL1, HL2,
The image region is divided into three regions according to the brightness of the cover 2D code image: brighter module region \( b \), darker module region \( d \), and edge (intermediate bright) region \( e \).

If \( v_{p,b,r} \) is higher than 0.5, then subband \( b \) of image region \( r \) is used to embed or extract the watermark. The embedding/extraction strength is determined by the following equation:

\[
L_{p,b,r} = \begin{cases} 
2 \times (v_{p,b,r} - 0.5) \times L_{\text{max}} & \text{if } v_{p,b,r} > 0.5 \\
0 & \text{otherwise}
\end{cases}
\]

If \( v_{p,b,r} \) is below 0.5, subband \( b \) of image region \( r \) is not used for embed/extraction.

The target problem has totally 60 dimensions, which is considerably larger than the problem with 21 dimensions in the previous work (Ono et al., 2014).

### 3.3.2 Objective Function

The proposed method designs semi-fragile watermark; the desirable semi-fragile watermark is extracted only from valid 2D code and not from replicated one. Therefore, semi-fragileness is represented by the watermark extraction accuracy difference between valid and replicated 2D code images. BCR denotes the pixel-wise coincidence ratio between two images.

\[
f(I) = \text{BCR}(W, W^{\text{valid}}) - \text{BCR}(W, W^{\text{replicated}})
\]

where \( W \) denotes digital watermark image, and \( W^{\text{valid}} \) and \( W^{\text{replicated}} \) are extracted watermark images from valid and replicated 2D code images, respectively. \( P(Y^{\text{valid}}) \) is a penalty function which is calculated based on error correction usage ratio of the captured cover 2D code \( Y^{\text{valid}} \).

### 3.4 Two-stage Optimization

As described in Sec. 3.3.1, the target problem involves 60 design variables, in which it is not easy to find the global optimum. In addition, the subbands which are used for embedding watermark are essentially used when also extracting. Therefore, the proposed method utilizes two-stage optimization. In the first stage, the embedding and extracting strength \( v_{\text{em,b,r}} \) and \( v_{\text{ex,b,r}} \) are optimized without any distinction as \( v_{\text{em,b,r}} = v_{\text{ex,b,r}} \) to reduce the search space. Then, in the second stage, all 60 variables are discriminated and simultaneously optimized. The first stage takes first \( T_g \) generations of the search, and then the second stage does during \( T_e \) generations. The best solution of the first stage is used as part of initial solutions of the second stage, resulting in an improvement of both accuracy and search efficiency.

### 4 EVALUATION

#### 4.1 Experimental Setup

To verify the effectiveness of our method, experiments were conducted with actual mobile phones (SHARP ISW16SH equipped with 4.6 inch 720 ×
4.2 Experimental Results

Fig. 8 shows the transitions of the best individual in the population during the two-stage optimization. The dotted lines denote the fitness values of independent runs, and the solid line describes the averaged value. Fig. 8 demonstrates that the second-stage search succeeded in finding better individuals than the best individual of the first-stage. In addition, the fitness of the best individual kept increasing even at around 400 generations, whereas the first-stage search converged after 100 generations; longer generation in the second stage would lead better solution.

The fitness value of the best solution exceeded 0.3, which was calculated from BCR values of the watermark images extracted from genuine and replicated 2D codes that were about 0.8 and 0.5, respectively. This means that the watermark can be decoded only from the genuine 2D code when the watermark 2D image is encoded with some error correctable code which corrects more than 20 percent of the code.

Figs. 9 and 10 show example watermark schemes $S_{1st}$ and $S_{2nd}$ that correspond to best individuals (solutions) in the first- and second-stage, respectively. In both solutions, watermark images from replicated images were destroyed and only slight bleeds were left, whereas genuine successfully kept watermark patterns. As shown in Figs. 9(i) and 10(i), in watermark images extracted from original 2D codes, the watermark extracted by $S_{2nd}$ involved less noise (black pixels) at white modules of watermark 2D code than that by $S_{1st}$. In addition, in watermark images extracted from replicas, $S_{2nd}$ successfully removed the horizontal component of watermark better than $S_{1st}$, as shown in Figs. 9(j) and 10(j).

Table 2 shows the details of $S_{1st}$ and $S_{2nd}$ whose outputs were shown in Figs. 9 and 10. Focusing on the bright region of the cover 2D code image, the scheme $S_{2nd}$ designed by second-stage search embedded the watermark into HH2, HL1, LH2, and LH3, whereas the first-stage solution $S_{1st}$ embedded the watermark mainly into HL1; and $S_{2nd}$ reconstructed the watermark from all the highest frequency subbands HH1, HL1, and LH1. This subband combination allows to facilitate the watermark destroy by replication at regions white circle modules of the covered 2D code.

In contrast, at dark region, $S_{2nd}$ weakly embedded the watermark into HL1 only. However, the watermark was extracted from HH1 and HH3 in addition to HL1. This is because watermark embedded into HL1 gave rise to irregular but frequent vertical pattern as shown in Fig. 10(g), and this weak watermark was easily destroyed by replication.

In the case of edge regions of the cover 2D code image which were smaller than other regions, $S_{2nd}$ used HL1 only similar to the dark region, whereas $S_{1st}$ used HH1 and LH1. $S_{2nd}$ reconstructed the watermark from HH1, HH2, HL1, and LH2. Similar tendency to the dark module regions could be seen in the edge regions.

5 CONCLUSIONS

This paper proposes a method for designing semi-fragile watermark for detecting 2D code replication. To realize a watermarking scheme with appropriate semi-fragileness, we introduced a new optimization technique as follows:

- Distinguishing subbands/strength levels between when embedding and extracting the watermark, which facilitates watermark reconstruction from more subbands than used for embedding. This
Two-stage optimization, which allows to optimize subband selection and watermarking strength in both embedding and extracting scheme. Distinguishing embedding and extracting variables in the latter half of the search allows to efficiently find good solutions.

- Actual mobile phone based solution evaluation instead of simulation, which allows taking various

facilitates watermark extraction from images displayed on 2D code screens.

Table 2: Obtained solutions by two-stage optimization.

<table>
<thead>
<tr>
<th>Bright region</th>
<th>First-stage embed</th>
<th>HH1</th>
<th>HH2</th>
<th>HH3</th>
<th>HL1</th>
<th>HL2</th>
<th>LH1</th>
<th>LH2</th>
<th>LH3</th>
<th>LL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright region</td>
<td>First-stage extract</td>
<td>0.99</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Second-stage embed</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Second-stage extract</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

| Dark region | First-stage embed | 0.54 | 0.00 | 0.00 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dark region | First-stage extract | 0.00 | 0.00 | 0.00 | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Second-stage embed | 0.00 | 0.00 | 0.00 | 0.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Second-stage extract | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Edge region | First-stage embed | 0.95 | 0.00 | 0.00 | 0.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Edge region | First-stage extract | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Second-stage embed | 0.00 | 0.00 | 0.00 | 0.00 | 0.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Second-stage extract | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.94 | 0.00 | 0.00 | 0.00 | 0.00 |
factors such as optical transfer function, distortion and various noise models into account without constructing a simulation model.

In future, we plan to apply multi-objective optimization (Ono et al., 2014) to make watermarking schemes robust against mobile phone screen types.

ACKNOWLEDGEMENTS

Part of this work was supported by SCOPE (142110001) of Ministry of Internal Affairs and Communications (MIC), Japan. The authors also would like to thank A-T Communications, Co.,LTD., and DENSO WAVE Inc.

REFERENCES


