An Improved Anti-counterfeiting Printed QR Watermarking Algorithm Based on Self-Adaptive Genetic Algorithm

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Abstract. To solve watermarking parameters optimization problem and enhance anti-counterfeiting performance, a self-adaptive genetic algorithm is proposed and introduced to improve robust QR code watermarking scheme. In the improved scheme, we adaptively change the genetic algorithm procedure according to the relation between the maximum fitness value and the average fitness value of a population. With the improved genetic algorithm procedure, it is easier to get better diversity. In addition, mutation probability as well as crossover probability is adaptively modified to quickly seek out the optimal watermarking parameters. The tests indicate that the decoding rate of QR code noticeably increases without degrading detecting rate of digital watermark with the improved anti-counterfeiting printed QR code watermarking scheme.

1. Introduction

QR code has been widely used in more and more application fields. However, its anti-counterfeiting performance is still a critical problem to be solved for more potential applications. Digital watermark is regarded as a feasible technology to the problem, and it is introduced by many researchers[1-4]. Among the researches, anti-counterfeiting printed QR code watermarking scheme is one of the most difficult researching subjects. A printed QR barcode anti-counterfeiting technique was proposed in paper[5]. In the anti-counterfeiting watermarking scheme, the robust watermarks are inserted into all watermarking channels of non-overlapping rectangular areas in DWT domain, and the channel watermark is designed to compute distorting rates of all the channels. During the watermark detecting, the robust watermarks are estimated by a distortion-rates based linear function. With the watermarking scheme, the watermark detecting rate is greatly increased. However, such watermarking parameters as chaos keys kₘ, kₐ, and quantization coefficient Δ are blindly and randomly searched, and the selected parameters are not optimal ones. So the QR code detecting rates aren't very satisfactory.

In the field of digital watermarking, many artificial intelligence related Algorithms[7-10] are adopted to find out optimal watermarking parameters. This paper aims to improve printed QR anti-counterfeiting watermarking scheme based on paper[5] by introducing a self-adaptive genetic algorithm to optimize the watermarking parameters.

The rest of the paper is arranged as follows. In section 2, the anti-counterfeiting printed QR code watermarking scheme is briefly reviewed. And then an adaptive genetic algorithm is proposed in section 3. Based on the algorithm, we propose the improved anti-counterfeiting printed QR code watermarking scheme. To evaluate the anti-counterfeiting performance, several tests are made in section 4. Finally, conclusions are drawn in the last section.
2. Review of anti-counterfeiting QR barcode watermarking scheme

The anti-coutnerfeiting QR barcode watermarking scheme is illustrated in Fig.1[5]. In the watermarking scheme, the QR image is transformed into DWT domain which is equally partitioned into several channels for robust watermark embedding. In watermark inserting stage, zero channel watermarks of all channels are generated, and robust watermarks are inserted into all channels. In watermark detecting stage, channel distorting rates are computed based on the zero channel watermarks, and robust watermarks are extracted by a linear function of the distortion rates. More details about the watermarking scheme are described in reference[5].

As described in Fig.1(a), after watermark embedding, the watermarked one can’t be ensured to be successfully decoded. If it fails to decode the QR code, we have to randomly reset the watermarking such parameters as chaotic keys k_x, k_y, and quantization coefficient Δ. So in the scheme, searching for appropriate watermarking parameters costs a long period of time, and we can hardly obtain an ideal watermarked QR image. In the next section we propose a watermarking parameters optimization algorithm based on self-adaptive genetic algorithm to improve the anti-coutnerfeiting QR barcode watermarking scheme.

(a) Anti-counterfeiting robust watermark inserting

(b) Robust watermark detecting and QR code decoding

Figure 1. anti-counterfeiting QR barcode watermarking scheme
3. Improved scheme based on Self-adaptive genetic algorithm

3.1. General Scheme Based on Genetic Algorithm

In this section, genetic algorithm is introduced to optimize watermarking parameters $k_x$, $k_y$, and $\Delta$. The anti-counterfeiting watermark embedding scheme based on genetic algorithm is illustrated in Fig. 2, where gen is the number of iterations, and maxgen is the maximum number of iterations. The watermark extracting and QR barcode decoding scheme is the same as Fig. 1(b).

![General scheme based on genetic algorithm.](image)

3.2. Chromosome Encoding and Fitness Function

Watermarking positions in DWT domain are decided by real parameters $k_x$ and $k_y$, which are initial values of a logistic chaos sequence, and the robustness of watermarking algorithm is mainly dependent on quantization coefficient $\Delta$. In this subsection, we encode the watermarking parameters mentioned above into a chromosome of 48-bits binary string. Let $ch_1$, $ch_2$ and $ch_3$ are 16-bits binary coding of $k_x$, $k_y$ and $\Delta$ respectively, then the chromosome is described as Fig. 3.

![Chromosome encoding](image)

The PSNR is usually used to measure the difference between an testing image and its watermarked one. A larger PSNR means that the watermarking algorithm make the watermarked QR image more detectable. We employ PSNR as fitness function to evaluate QR code watermarking performance. So the fitness function is described as following.

$$\text{Max}(f(ch_1, ch_2, ch_3)) = \text{PSNR}(ch_1, ch_2, ch_3)$$  \hspace{1cm} (1)

3.3. Adaptive Genetic Algorithm Procedure

Crossover operation help us obtain good offspring by gene rebullding, and it is critical for searching global optimal watermarking parameters. On the other hand, mutation operation can generate new excellent genes which are absent in the parent population. By mutation operation we can effectively improve the diversity of a population.
Traditionally we make crossover operation prior to mutation operation in GA schemes. This algorithm procedure may cause fitness values of the population to mainly distribute in a narrow range, which leads to poor diversity. Let \( f_{\text{ave}} \) and \( f_{\text{max}} \) be the average fitness value and maximum fitness value of a population respectively. If \( f_{\text{max}} \leq 2f_{\text{ave}} \), it indicates that the fitness values concentratedly distribute in a narrow range, and that the diversity of the population is poor. In this case, we make mutation operation prior to crossover operation. Contrarily, if \( f_{\text{max}} > 2f_{\text{ave}} \), it indicates that the fitness values distribute in a wide range, and so we make crossover operation prior to mutation operation. The improved genetic algorithm procedure is detailly described as following.

Step 1: Coding the chromosome, producing an initial population at random, and setting the population size as well as the maximum number of generation.

Step 2: Computing the fitness values of all the individuals in the population.

Step 3: Making crossover operation, mutation operation, and selecting operation sequentially based on the relation between \( f_{\text{max}} \) and \( f_{\text{ave}} \) discussed above.

Step 4: Judging the terminal condition of the iteration, and going to step 2 if it is necessary.

Fig. 4 illustrates the algorithm procedure.

![Adaptive genetic algorithm procedure](image)

Mutation probability \( (P_m) \) and crossover probability \( (P_c) \) are two important parameters which greatly affect the algorithm performance. A bigger \( P_c \) leads to a greater diversity of the population. But too big \( P_c \) may destroy some excellent individuals. On the other hand, a bigger \( P_m \) makes the algorithm more easily jump out of local optimal solution and find the optimal one. But too big \( P_m \) may result in random searching.

This paper adaptively modifies \( P_c \) and \( P_m \) as following\(^6\).

\[
\begin{align*}
P_c &= \begin{cases} k_1(f_{\text{max}} - f_c)/(f_{\text{max}} - f_{\text{ave}}) & f_c \geq f_{\text{ave}} \\ k_2 & f_c < f_{\text{ave}} \end{cases} \\
P_m &= \begin{cases} k_3(f_{\text{max}} - f_m)/(f_{\text{max}} - f_{\text{ave}}) & f_m \geq f_{\text{ave}} \\ k_4 & f_m < f_{\text{ave}} \end{cases}
\end{align*}
\]

\( k_1, k_2, k_3, k_4 \in (0,1] \)

Where \( f_{\text{ave}} \) is the average fitness value, \( f_{\text{max}} \) is the maximum fitness value, \( f_c \) is the bigger fitness value among two crossover individuals, and \( f_m \) is the fitness value of a mutant individual.
4. Experiments

In this section we test the performance of the improved algorithm by evaluating decoding rate of QR barcode \( R_{qr} \) and detecting rate of digital watermark \( R_{wm} \). \( R_{qr} \) and \( R_{wm} \) are detailly introduced in paper[5].

\[
R_{qr} = \frac{N_{\text{pass}}}{N} \tag{4}
\]

\[
R_{wm} = \frac{\sum_{i=1}^{N} N_{i}}{\text{LEN} \times N} \tag{5}
\]

where \( N \) and \( N_{\text{pass}} \) are the number of total tests and the number of successful QR decoding tests respectively. \( \text{LEN} \) denotes the length of anti-counterfeiting robust watermark. In other words, it is the number of the total bits of the watermark. \( N_{i} \) is the correctly detected robust watermark bits number.

In the tests, anti-counterfeiting robust watermarks are embedded in 4 watermarking channels in DWT domain. Three testing QR images are displayed in Fig. 5 with different sizes of 180x180(pixels), 245x245(pixels), 318x318(pixels), respectively.

![Testing QR images](image)

Figure 5. Testing QR images

Two groups of tests are made to compare the \( R_{qr} \) and \( R_{wm} \) of this paper with those of paper [5]. The testing results given in Tab.1 shows that \( R_{qr} \) noticeably increases with the improved anti-counterfeiting QR watermarking scheme. In the watermarking scheme of paper [5], we search for watermarking parameters blindly, and the selected parameters are only suitable, but not optimal ones. But with the improved scheme of this paper, we can rapidly seek out the optimal watermarking parameters by adaptive genetic algorithm. Additionally, a larger size of QR image enable us obtain better \( R_{qr} \) , while more watermarking bits lead to worse \( R_{qr} \). The testing results shown in Tab.2 indicate that both \( R_{wm} \) in paper [5] and in this paper are similar, which means that the improved scheme doesn’t degrade watermarks detecting performance.

| QR image size(pixels) | Watermarking algorithm | Length of Watermark (bits) |
|-----------------------|------------------------|---------------------------|
|                       |                        | 32 | 64 | 128 | 256 |
| (a) 180x180           | Paper[5]               | 90% | 83% | 78% | 61% |
| (b) 245x245           | This paper             | 100% | 97% | 85% | 78% |
| (c) 318x318           | Paper[5]               | 100% | 100% | 90% | 85% |
|                       | This paper             | 100% | 91% | 86% | 82% |

Table 1. \( R_{qr} \) comparisons
Table 2. $R_{wm}$ comparisons

| QR image size(pixels) | Watermarking algorithm | Length of Watermark (bits) |
|-----------------------|-------------------------|---------------------------|
|                       |                         | 32           | 64           | 128        | 256        |

(a) 180x180
- Paper[5] 92% 87% 73% 61%
- This paper 93% 87% 72% 63%

(b) 245x245
- Paper[5] 95% 91% 87% 76%
- This paper 95% 92% 89% 77%

(c) 318x318
- Paper[5] 96% 92% 89% 79%
- This paper 98% 93% 92% 82%

5. Conclusion

Watermarking parameters are critical factors in image watermarking scheme, and how to choose optimal watermarking parameters is a long-standing problem. In the existing anti-counterfeiting printed QR code watermarking algorithm, the watermarking parameters are blindly and randomly searched, and the selected parameters are only suitable, but not optimal ones. This paper introduces genetic algorithm to optimize such watermarking parameters as chaos keys $k_x$, $k_y$, and quantization coefficient $\Delta$, and proposes an adaptive genetic algorithm procedure, with which we can get better diversity of a population and quickly find out the optimal watermarking parameters. Testing results indicate that, for different sizes of QR images, $R_{qr}$ (s) are greatly improved, while $R_{wm}$ (s) don’t degrade.

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