Optics Communications 282 (2009) 2806–2817

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Improving the performance of DCT-based fragile watermarking using intelligent optimization algorithms

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ARTICLE INFO

Article history:
Received 23 September 2008
Received in revised form 15 April 2009
Accepted 16 April 2009

PACS:
42.30.Rx
42.30.Wb
42.30.Va

Keywords:
Fragile watermarking
DCT
Genetic algorithm
Differential evolution algorithm
Clonal selection algorithm
Particle swarm optimization algorithm

ABSTRACT

The performance of a fragile watermarking method based on discrete cosine transform (DCT) has been improved in this paper by using intelligent optimization algorithms (IOA), namely genetic algorithm, differential evolution algorithm, clonal selection algorithm and particle swarm optimization algorithm. In DCT based fragile watermarking techniques, watermark embedding can usually be achieved by modifying the least significant bits of the transformation coefficients. After the embedding process is completed, transforming the modified coefficients from the frequency domain to the spatial domain produces some rounding errors due to the conversion of real numbers to integers. The rounding errors caused by this transformation process were corrected by the use of intelligent optimization algorithms mentioned above. This paper gives experimental results which show the feasibility of using these optimization algorithms for the fragile watermarking and demonstrate the accuracy of these methods. The performance comparison of the algorithms was also realized.

1. Introduction

There has been an explosion in the use and distribution of the multimedia data such as digital image, audio and video due to the rapid development of computers and communication networks. These data can be easily copied and altered or even stolen. Therefore, a great deal of concern has grown about the protection of these data. Digital watermarking is one of the new methods which provide protection for the digital data by embedding secret information directly into the data. This secret information is known as the watermark and used for several reasons such as content authentication, fingerprinting, copyright protection, content archiving, broadcast monitoring and tamper detection [1].

Digital image watermarks can be categorized into two main groups; visible and invisible. Visible watermarks are the ones which can easily be perceived by the viewer. They are visual patterns like logos embedded into one side of an image [2]. Logos or visible watermarks can not only be identified, but also be removed or destroyed easily. On the other hand, invisible watermarks are embedded on the unknown sides of the images and are more robust than visible watermarks. Namely, they cannot be perceived under normal viewing conditions. Only the authorized people can extract the embedded watermark.

With respect to robustness, invisible watermarks can be classified as robust, semi-fragile and fragile [2]. Robust watermarks can resist some image manipulations called attacks such as scaling, cropping, compression, etc. Semi-fragile watermarks can be destroyed only when user-specified threshold is exceeded. Fragile watermarks can easily be demolished if a slight change occurs on the host image. As a result, unauthorized modifications on the watermarked images can be detected. That is why fragile watermarking methods are mainly used for the purpose of image authentication in the area of satellite or medical imagery.

Moreover, fragile watermarking techniques can also be divided into two classes: spatial domain and frequency domain. In the spatial domain, watermarks are embedded by modifying the pixel values directly [3–5]. The advantage of using the spatial domain watermarking is that its application is done very easily. However, the main disadvantages of the techniques used in early fragile watermarking systems are the easiness of bypassing the security they provide [6,7] and the failure of lossy compression of the image without damaging the watermark [8]. On the other hand, in the frequency domain, watermarks can be embedded by modifying

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doi:10.1016/j.optcom.2009.04.034

the transform coefficients of discrete cosine transform (DCT) [9–13] and discrete wavelet transform [14–16]. The main advantages of using the frequency domain methods are that they can easily be adapted to lossy compression systems, which have the ability to embed data in the compressed representations, and have ability to reveal how an image has been damaged or altered.

In recent years, the performances of digital watermarking methods have been improved using artificial intelligence techniques such as genetic algorithm (GA) [12,17–27], genetic programming [28,29], clonal selection algorithm (CSA) [10], particle swarm optimization (PSO) algorithm [11,30,31], differential evolution (DE) [32] and neural networks [33–36]. In DCT based fragile watermarking techniques, the original input image is first transformed into its frequency domain. Then, the watermarks are generally embedded by modifying the least significant bits (LSBs) of the frequency domain coefficients. After the embedding process is completed, transforming the modified coefficients from the frequency domain to the spatial domain produces some rounding errors due to the conversion of real numbers to integers. In the literature, there are a few studies to reduce rounding errors that occur during the transformation process of DCT based fragile watermarking techniques. This problem was addressed by Shih and Wu [12] using GA to find a guiding bit map for whole host image. The guiding bit map is used to direct the pixel value's carrying and truncation, which is to replace the rounding operations. However, the effectiveness of this technique highly depends on the guiding bit map. In [13], a heuristic method was proposed to enhance the quality of the extracted watermark. The host image is divided into nonoverlapping blocks, and the pixel values are modified by using the reference coefficient data. The method proposed in this paper is superior to these methods in terms of the NC (Normalized Cross Correlation) value of the extracted watermark and the PSNR (Peak Signal to Noise Ratio) of the watermarked image. The NC value is always 1, which is not the case with the methods proposed in [12,13].

This paper is organized as follows: In Section 2, the fundamental concepts of IOA are described. Section 3 demonstrates the traditional DCT based fragile watermarking method. In Section 4, IOA based methods which correct the rounding errors are demonstrated. Section 5 demonstrates the simulation results and performance comparison of the algorithms. Finally, Section 6 concludes the paper.

2. Intelligent optimization algorithms (IOA)

In this paper, GA, DE, CSA and PSO algorithms are used to improve the performance of the fragile watermarking technique. In the following subsections, a brief explanation of each algorithm is given.

2.1. Fundamental concepts of GA

GA, invented by Holland [37], is a popular evolutionary optimization algorithm. This algorithm can find the global optimal solution in complex multidimensional search spaces. GA is modeled based on the theory of natural evolution in that the operators it employs are inspired by the natural evolution process. These operators, known as genetic operators, manipulate individuals in a population over several generations to improve their fitness gradually. The main steps of a basic GA are given below [38]:

(1) Initialization,
(2) Evaluation,
(3) Reproduction,
(4) Crossover,
(5) Mutation,
(6) Repeat steps 2–5 until stopping criteria is reached.

A basic GA includes five components that are a random number generator, fitness evaluation unit and genetic operators for reproduction, crossover and mutation operations. The initial population required at the start of the algorithm is a set of bit strings generated by the random number generator. Each string is a representation of a solution to the optimization problem being addressed. Associated with each string is a fitness value computed by the evaluation unit. A fitness value is a measure of the goodness of the solution that it represents. The aim of the genetic operators is to transform the set of strings into sets with higher fitness values.

The reproduction operator performs a natural selection function known as "seeded selection". Individual strings are copied from one set (representing a generation of solutions) to the next according to their fitness values; the higher the fitness value, the greater the probability of a string being selected for the next generation. The crossover operator chooses pairs of strings at random and produces new pairs. The simplest crossover operation is to cut the original "parent" strings at a randomly selected point and exchange their tails. The number of crossover operations is governed by a crossover rate (Cr). The mutation operator randomly mutates or reverses the values of bits in a string. The number of mutation operations is determined by a mutation rate. A phase of the algorithm consists of applying the evaluation, reproduction, crossover and mutation operations. A new generation of solutions is produced with each phase of the algorithm.

2.2. Fundamental concepts of DE algorithm

DE algorithm is a population based algorithm which uses the operators similar to the genetic algorithm in the process of crossover, mutation and selection. This algorithm can be categorized as a floating-point encoded evolutionary algorithm. The algorithm uses the mutation operation as a search mechanism and the selection operation to direct the search towards the optimum region. The main operation of the algorithm is based on the differences of randomly sampled pairs of vectors in the population [39]. The main steps of the DE algorithm are given below [40]:

(1) Initialization,
(2) Evaluation,
(3) Mutation,
(4) Recombination,
(5) Evaluation,
(6) Selection,
(7) Repeat steps 3–6 until stopping criteria is reached.

DE algorithm works by creating an initial population. An individual of the population is selected at random for replacement and other three different individuals are selected at random as parents. In DE algorithm, a uniform probability distribution for all random decisions is used. With some probability, each variable in the parent is changed. The change is accomplished by adding the multiplication of F (scaling factor) with the difference of other two parents to generate a candidate child vector. For this purpose, several strategies were proposed in [41], namely DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/randtobest/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/randtobest/1/exp. DE/x/y/z indicates DE for Differential Evolution, x is a string which denotes the vector to be perturbed, y denotes the number of difference vectors taken for perturbation of x, and z is the recombination method [42]. The changing process represents the recombination operation in DE algorithm. The operation of DE algorithm is formulized below:

$$X_{i,j}^{(G+1)} = \begin{cases} X_{C_i,j}^{(G)} + F \times (X_{A_i,j}^{(G)} - X_{B_i,j}^{(G)}) & \text{if } r_{i,j} \leqslant RC_r \vee j = D_i \\ X_{i,j}^{(G)} & \text{otherwise} \end{cases} \quad (1)$$