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Optimized Watermarking Using Swarm-Based Bacterial Foraging

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Abstract. *Digital watermarking has been a popular topic in both scientific research and applications in the last decade. Based on previous experiences for the development of watermarking algorithm in literature, there are lots of requirements that need to be considered based on the purpose for applications. Therefore, how to assess the effectiveness of the algorithm should be based on the preset requirements. Here we use a recent optimization technique, named bacterial foraging, to search for the tradeoff among requirements, and we employ the concept in fuzzy theory to design an effective fitness function with the pre-determined requirements. Unlike conventional scheme to fix the components in the fitness function, by using the fuzzy concept in conjunction with swarm intelligence, better results could be obtained. Simulation results demonstrate the advantages of the proposed algorithm over existing ones in the literature.*

Keywords: Watermarking, Bacterial foraging, Swarm intelligence.

1. **Introduction.** Data watermarking is a way to effectively embed the secret data into the cover media, including audio, video, and image. The major purpose for watermarking is to perform the copyright protection of original contents, and hence to preserve the ownership of content creators. Due to the ease of delivery and modification of digital files, the copyrights might be infringed upon. To deal with this problem, digital rights management (DRM) systems can prevent users from using such contents illegally, and watermarking research and applications have become a major topic in the last decade. With the major purposes for copyright protection or data authentication, its process usually introduces irreversible degradation of the original multimedia [1, 2].

The watermarking algorithms that are suitable for copyright protection are called "robust watermarking" algorithms. For robust watermarking, the secret data is first hidden into the original multimedia by using the pre-defined watermarking algorithm, and the watermarked multimedia is obtained. Next, the watermarked multimedia is expected to experience intentional or unintentional signal processing schemes, called attacks, including recompression, enhancement, or data loss during transmission. After experiencing attacks, partly of the hidden data should be extracted from the attacked watermarked multimedia. If the extracted hidden data is recognizable, the pre-defined algorithm can be classified as robust watermarking, which is one of the current major topics in watermarking research.

As evident from the literature [3, 4], in order to design a good watermarking algorithm, there are lots of requirements that should be mostly met. The commonly encountered requirements that are mostly considered are the watermarked image quality (or imperceptibility), the survivability, represented by the correct rate of extracted watermark (or robustness), and the number of bits embedded (or capacity). As demonstrated by Huang et al. [3], some trade off must be searched for because the three requirements conflict with each other.

We try to search for the tradeoff between watermark imperceptibility and watermark robustness with the aid of an optimization technique named bacterial foraging. Unlike conventional ways for performing optimization using genetic algorithm (GA), bacterial foraging is a very recent swarm intelligence technique, which is inherently different from the GA meta-heuristic. In addition, the concept of fuzzy theory is also included into the design of fitness function. Since genetic algorithm has been used to find an optimized solution for watermarking, by the use of fuzzy-based bacterial foraging, we provide another scope to solve this problem, and better results can be judged objectively.

Rest of the paper is organized as follows. In Section 2, we discuss the concepts and implementation of both the histogram-based scheme and the difference expansion technique. We also provide comparisons between the two schemes. In Section 3, we then describe the proposed algorithm by integrating the histogram-based scheme into difference expansion. Simulation results are demonstrated in Section 4. Finally, we point out the contributions of the proposed algorithm and conclude the paper in Section 5.

2. Background Descriptions of Bacterial Foraging and Fuzzy Concepts.

We use the digital images to represent the multimedia contents in this paper. By the use of bacterial foraging (BF) and fuzzy concepts, the optimized outcome for image-based watermarking can be obtained.

2.1. The use of bacterial foraging for watermarking.

As stated in Sec. 1, the watermarked image quality, the capability to resist against attacks, and the number of embedded bit (or capacity) should be included into the proposed optimization process. Considering practical applications, we set the watermark capacity a constant value, and we try to search for the tradeoff between watermark imperceptibility and watermark robustness. By following existing research work reported in the literature, the conflicts between the two can be briefly summarized as follows.

- **Imperceptibility**: To make the watermarked image imperceptible, the watermark should be hidden into less significant parts, such as the least significant bits in the spatial domain or the high frequency components in the transform domain. Figure 1 shows the magnitude distribution of DCT coefficients for the test image Lena. We can see that larger magnitudes are concentrated into lower frequency bands; thus, by modifying the lower bands for watermarking, it may lead to larger induced error.

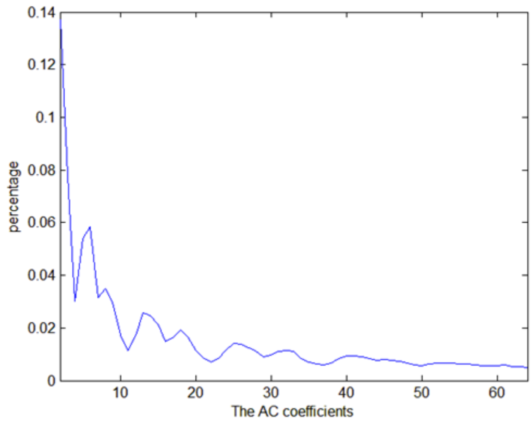


FIGURE 1. The distribution of magnitudes of DCT coefficients for the test image `Lena`.

It is generally agreed to hide the data into higher frequency bands to get better imperceptibility.

- **Robustness**: The watermarked media need to withstand the attacks mentioned above. To make the algorithm robust, the watermark needs to be hidden into more important parts of the media, as demonstrated in Figure 1. Hence, better robustness can be expected if the data is hidden into lower frequency bands.

As evident from the two items above, for one robust watermarking algorithm, better values for both imperceptibility and robustness are desired under the condition of a fixed number of capacity, but they have conflicts in the bands for embedding the watermark. By employing bacterial foraging, our algorithm needs to meet the following conditions: (1) lower error (generally denoted by the mean square error, or MSE), and (2) better robustness (denoted by the bit correct rate, or BCR). The design of the fitness function should be carefully monitored as well. Learning from the concepts reported in the literature [3, 4], the design of the fitness function is given in Eq. (1).

$$f_i = \mathrm{PSNR}_i + \lambda \cdot \mathrm{BCR}_i, \tag{1}$$

where f_i denotes the fitness value for iteration number i, and PSNR_i and BCR_i means the peak signal-to-noise ratio and bit correct rate for iteration number i, respectively, and λ denotes the weighting factor to balance the effects from the conflicting conditions of imperceptibility and robustness. Generally speaking, the PSNR value should be greater than 30, while the BCR value lies between 0 and 1. Therefore, the inclusion of weighting factor is necessary. It is evident that the PSNR and BCR directly correspond to the imperceptibility and the robustness for the design of the watermarking algorithm.

The major purpose for using bacterial foraging is to obtain the optimized embedding bands for hiding the watermark information. Figure 2 depicts the flowchart for robust watermarking using bacterial foraging using the three major building blocks. Even though the origin for designing the fitness function in this paper is similar to the existing ones [3, 4], the concept and implementation here are much different from those reported in the literature. Bacterial foraging is a swarm intelligence technique inspired from the foraging behavior of E. Coli bacteria and is composed of three major building blocks as follows:

- Chemotaxis,
- Mutation, and

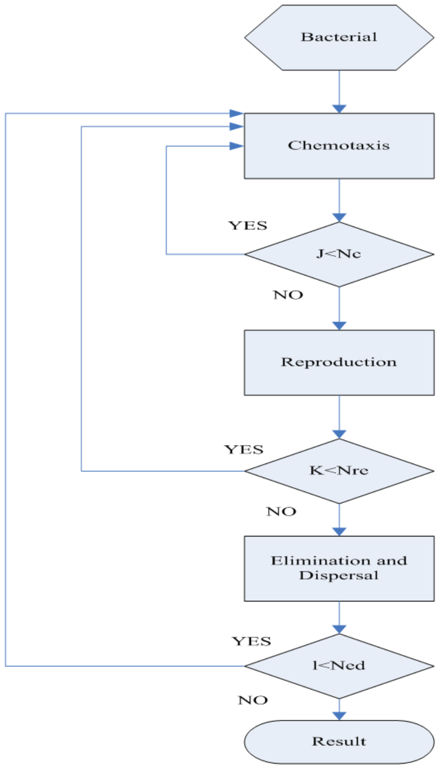


FIGURE 2. Procedure flow for robust watermarking with bacterial foraging.

- Reproduction.

We can see that chemotaxis, by using the concept of swarm intelligence, is different from the conventional genetic algorithm. Hence the 8×8 DCT is employed for performing watermarking, the 64 positions for DCT coefficients can be numbered from 0 to 63. Since we are going to obtain the optimized positions for embedding, by use of the proposed algorithm to be described in Section 3, position 0 is forbidden to be used, and positions 1 to 63 are selected by bacterial foraging algorithm. The chemotaxis procedure is described using the example below.

Suppose that the sizes for original image and the binary watermark are $M \times N$ and $m \times n$, respectively and let the matrix for the appropriate positions for embedding be represented by a matrix $\mathbf{H}$ with the size of $\frac{M \cdot N}{64} \times \frac{m \cdot n}{M \cdot N \cdot \frac{1}{64}}$. The chemotaxis processes can be described in the following steps.

Step 1.: *Range selection.* Two range parameters, R_1 and R_2, are selected, with the conditions that $R_1 > R_2 + 2$ and $R_1, R_2 \in [2, 62]$. The conditions are set to make the training of bacterial foraging algorithm possible.

Step 2.: *Bacteria formation.* The matrix $\mathbf{H}$ is split into vectors $H_{(i)}$ with sizes of $\frac{M \cdot N}{64} \times 1$, $i \in \left[1, \frac{m \cdot n}{M \cdot N \cdot \frac{1}{64}}\right]$.

Step 3.: *The chemotaxis process: position perturbation and moving.* The elements in the vectors $H_{(i)}$ are intentionally perturbed, with the conditions below, based on the parameters of R_1 and R_2 in Step 1.

- If elements in $H_{(i)}$ are smaller than R_1, they are added by random numbers and the new values should fall into the range of $[0, 63 - R_1]$.
- If elements in $H_{(i)}$ lie between R_1 and R_2, they are added by random numbers and the new values should fall into the range of either $[2 - R_1, 0]$, or $[0, 63 - R_2]$.

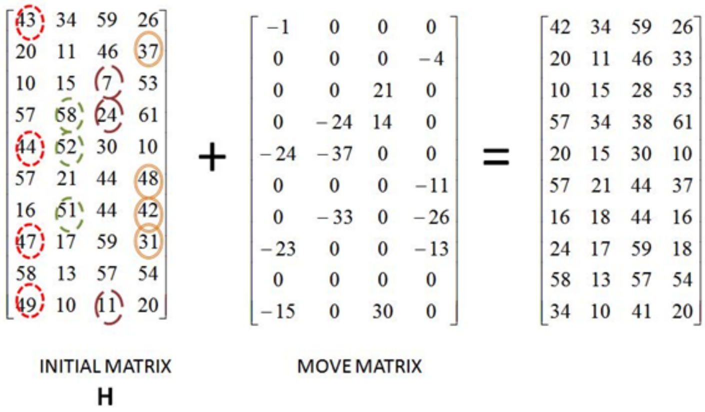


FIGURE 3. One example for the chemotaxis procedure.

- If elements in $H_{(i)}$ are larger than R_2, they are added by random numbers and the new values should fall into the range of $[1 - R_2, 0]$.

Figure 3 gives an example for the chemotaxis process. By setting $R_1 = 28$ and $R_2 = 49$, the positions to be perturbed, marked by circles, should fit any one of the conditions in Step 3. The initial matrix is perturbed by a matrix, and the resulting matrix is ready for training in the next step.

Step 4.: *Mutation.* The values of some elements in the output matrix are intentionally altered, called mutation, to search for the opportunity to escape from locally optimal results.

Step 5.: *Reproduction.* Bacteria with less fitness values should disappear, and those with better fitness values should be split into two parts, and start the training process again.

2.2. **Fuzzy concepts for the design of fitness function.** As evident from Eq. (1), the weighting factor λ is employed to balance the effects from imperceptibility and robustness. However, with the schemes available in the literature, the weighting factor is fixed to a constant, and how to choose the values of λ may come from heuristics. In this paper, we use the membership function in fuzzy theory to adaptively adjust the value of λ.

3. **Proposed Schemes.** Here we describe the watermarking algorithm with fuzzy-based bacterial foraging.

3.1. **Parameter selection for bacterial foraging.** Before training, parameters including the number of bacteria S, the number of steps in chemotaxis N_c, the mutation probability p_m, the number of bacteria for reproduction N_r, and the number of training iterations t, should be determined. In this paper, we set $S = 50$, $N_c = 10$, $p_m = 0.05$, $N_r = 10$, and $t = 50$.

3.2. **Watermark embedding with DCT.** Conventional watermark embedding scheme in the DCT domain in [4] is employed for making comparisons.

3.3. **Performing attacks.** Three attacks, including the JPEG, median filtering (MF), and low-pass filtering (LPF) are performed to test the robustness of the algorithm.

3.4. **Integration with bacterial foraging.** The chemotaxis, mutation, and reproduction procedures in bacterial foraging algorithm are performed sequentially to obtain the watermarked image quality and robustness with the trained positions for embedding.

Table 1. Comparisons of imperceptibility and robustness, represented by PSNR (in dB) and BCR, between our algorithm and existing one with test image Lena.

Scheme	Imperceptibility	Robustness			Mostly embedded band
		JPEG	LPF	MF	
Fuzzy	45.83	0.8911	0.7623	0.7502	AC10
$\lambda = 50$	39.09	0.8825	0.7498	0.7025	AC8
$\lambda = 100$	37.29	0.8910	0.8355	0.7669	AC13
Existing [4]	34.79	1.0000	0.7947	0.7426	AC9

3.5. **Fitness evaluation with fuzzy set.** The fitness function in Eq. (1) can be slightly modified by

$$f_i = \mathrm{PSNR}_i + \lambda \cdot \mathrm{BCR}_i, \tag{2}$$

where λ_i denotes the weighting factor for iteration number i, which is obtained by fuzzy membership function. With Eq. (2), bacterial foraging optimization algorithm is performed for obtaining the optimized outcome.

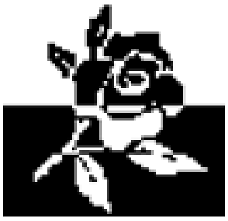
3.6. **The termination condition.** Once the predetermined training iteration is reached, the training procedure is terminated, and the optimized positions for embedding along with the watermarked output and associated robustness measures can be obtained.

4. **Experimental Results.** We have conducted several experiments to examine the effectiveness of the proposed algorithm. We choose the test image Lena for making tests with the combinations of preset parameters. Performances with bacterial foraging (BF) optimization algorithms only and that with the fuzzy concept are also compared. Figure 4 illustrates the extracted watermarks after BF training with or without the fuzzy-based method for adjusting the weighting factor λ. With the fuzzy-based scheme, the BCR values after the three attacks are larger than that with the fixed-weighting case when $\lambda = 50$. For subjective quality of extracted watermarks, the rose can be recognizable, but with fuzzy-based scheme, the qualities might be somewhat better.

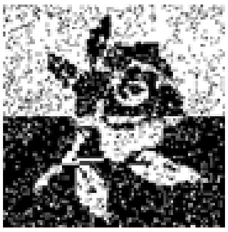
In Figure 5, we demonstrate the fitness in Eq. (2) with the number of iterations. From the illustrated results, even though all the three values of PSNR, BCR, and weighting factor may fluctuate, we still observe that the sum of Eq. (2) keeps increasing. For comparing with the existing results by training with GA, we provide another comparison in Table 1. We can see that with BF, whether fuzzy theory is employed or not, the proposed framework performs better than their counterparts by training with GA. Moreover, with the fuzzy-based scheme for adjusting the weighting factor, better results with corresponding numerical values can be presented.

Regarding to the bands for embedding the watermark, as we mentioned in Sec. 1, the middle frequency bands tend to be the better choice for embedding. We can see that by incorporating the fuzzy concepts, the mostly embedded band is the 10th AC band, while that with $\lambda = 50$ and $\lambda = 100$ are located at the 8th and 13th AC bands, respectively. According to [4], the mostly embedded band is the 9th AC band. As evident, the embedded bands corresponding to different training conditions differ a little bit, and they all fit the concept for embedding since they all locate at the middle frequency bands.

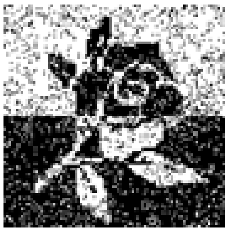
Summing up, with the concept of fuzzy theory, better results with bacterial foraging optimization algorithm can be obtained. Since bacterial foraging is a kind of optimization technique based on swarm intelligence, it is inherently different from genetic algorithm.



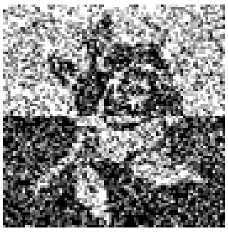
(a) Embedded watermark with size 128 × 128



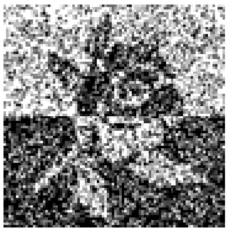
(b) BCR = 0.8911



(c) BCR = 0.8825

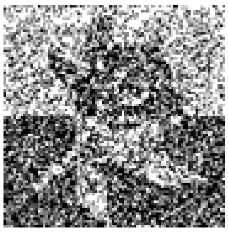


(d) BCR = 0.7623



(e) BCR = 0.7498

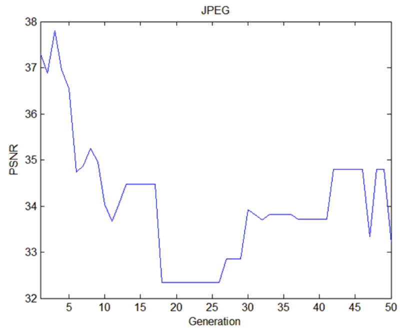
(f) BCR = 0.7502



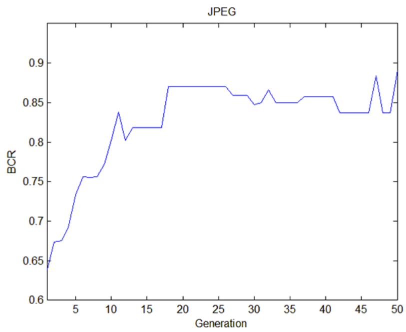
(g) BCR = 0.7025

FIGURE 4. (a): Embedded binary watermark with size 128 × 128. (b), (d), (f): Extracted watermarks with fuzzy-based BF under JPEG, MF, and LPF attacks. (c), (e), (g): Extracted watermarks with BF, $\lambda = 50$, under JPEG, MF, and LPF attacks.

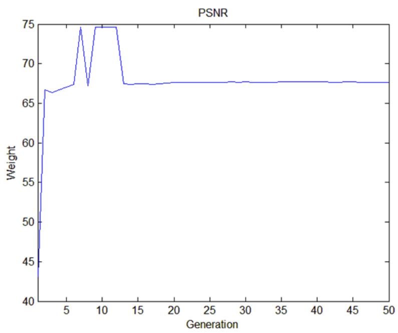
5. **Conclusions.** In this paper, we presented the optimization of robust watermarking using bacterial foraging optimization algorithm. By finding tradeoffs among different watermark robustness and imperceptibility, and considering the adaptive tuning of weighting factors, we design a practical fitness function for optimization. Simulation results depict the better performances over existing implementations with GA, and hence fuzzy-based BF can be considered to be another practical optimized watermarking scheme .



(a)



(b)



(c)

Figure 5. Evolutions of parameters in the fitness function for JPEG attack. (a) PSNR. (b) BCR. (c) The weighting factor.

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