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Survey of Bio-inspired Computing for Information Hiding

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Abstract. *In this paper, we performed surveys of bio-inspired techniques for information hiding. The applications of bio-inspired optimization for information hiding or watermarking have emerged in early 2000's. Due to the flexibility of algorithm designs, parameter selections, and performance metrics, the uses of bio-inspired optimization techniques provide effective solutions for information hiding. Relating schemes from different papers in literature are extensively surveyed and are briefly discussed. This survey aims at providing the background knowledge for further researches in this field.*

Keywords: Information hiding, Watermarking, Bio-inspired optimization.

1. **Introduction.** With the widespread use of wireless connections and the emergence of Internet of Things (IoT), the demand for copyright protection of multimedia has become an important issue [1, 2]. One of the effective means would be information, including watermarking and steganography. The modern digital watermarking technology has a rather short history since 1993 [3].

A typical application of digital watermarking is to identify the ownership of multimedia contents by embedding the owner mark, or the *watermark*. Typically, most multimedia

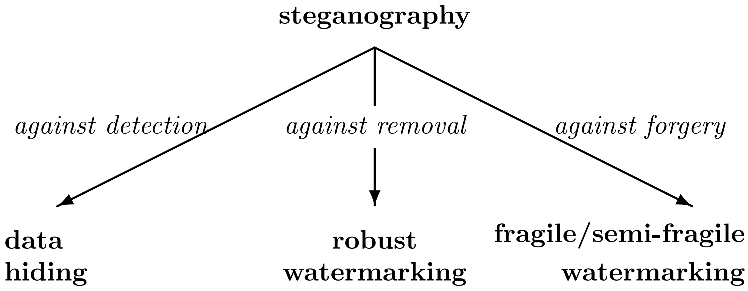

FIGURE 1. The classification for watermarking as depicted in [4].

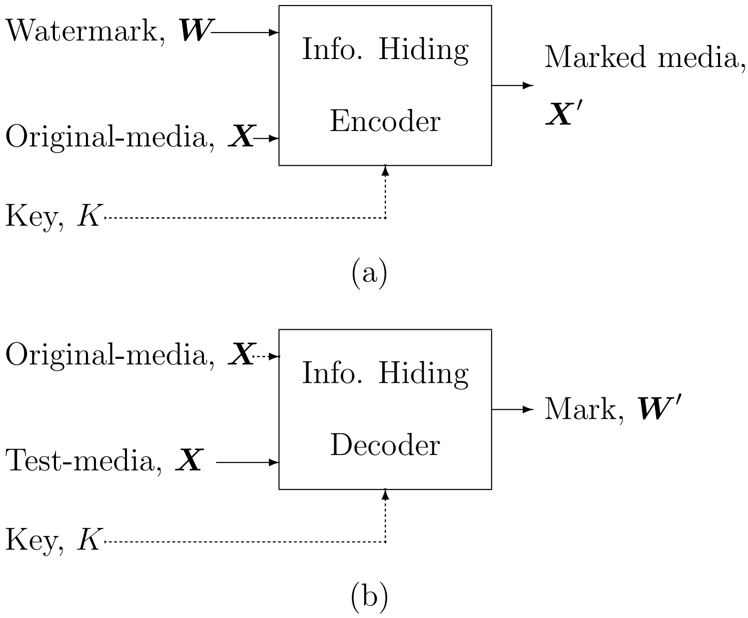

FIGURE 2. The block diagrams for information hiding [1, 2]. (a) Information insertion. (b) Information extraction.

applications require imperceptible and robust watermark. In addition, there are other demands that may require perceptible or fragile watermarking. Some terminology and relating classifications are described in Fig. 1.

The high level diagram of a generic watermarking scheme is depicted in Fig. 2. Typically, in a watermark insertion process shown in Fig. 2(a), we have the original media ($\boldsymbol{X}$), an image for example, and the encoder inserts a watermark ($\boldsymbol{W}$) into it. The result is the marked media $\boldsymbol{X}'$, for example, a marked image. In this embedding, process, a key may be involved to produce a more secure watermark. This key may be regarded as a portion of the encoding process. The dashed line in Fig. 2 indicates that it may be needed for a particular design. At the other end, the watermark is either extracted by a decoder, illustrated in Fig. 2(b). In addition to the test media ($\boldsymbol{X}$), the original media and/or a key may be needed.

We also use mathematical notions to express the aforementioned processes in Fig. 2. We can view the *embedding* process as a function or mapping that maps the inputs $\boldsymbol{X}$, $\boldsymbol{W}$ and/or K to the output $\boldsymbol{X}'$; that is,

$$\boldsymbol{X}' = E(\boldsymbol{X}, \boldsymbol{W}, [K]), \tag{1}$$

where $E(\cdot)$ denotes the embedding process, and $[K]$ indicates that K may not be included. Similarly, the *decoding* or *extraction* process, $D(\cdot)$, can be denoted by

$$\boldsymbol{W}' \;=\; D(\boldsymbol{X}, [\boldsymbol{X}], [K]). \tag{2}$$

Again, $[\cdot]$ means that the element in the bracket may be optional.

Here is an example for precise demonstration in Eq. (1). Suppose that

$$\boldsymbol{X}'_i \;=\; \boldsymbol{X}_i + \alpha \cdot \boldsymbol{W}_i,\; i \in 1, 2, \cdots, N. \tag{3}$$

We can observe the subscript, i, denotes the selected positions for information hiding. Besides the impression that $\boldsymbol{X}$ and $\boldsymbol{X}'$ imply the contents in the spatial domain for images, they can also be represented in the frequency domain, for instance, discrete cosine transform (DCT) or discrete wavelet transform (DWT) domains, or in the temporal domain if they are audio or video signals. Furthermore, N denotes the length of the watermark, and α means the embedding strength for watermarking. We infer from Eq. (3) that with the increase of N and α values, the differences between $\boldsymbol{X}$ and $\boldsymbol{X}'$ becomes large. Finally, the positions for information hiding added another flexibility for the design of algorithm, and the key $[K]$ plays the role for decoding. Besides the developments of algorithm design, practical applications can also be observed in literature [5, 6].

The rest of the paper is organized as follows. In Sec. 2, we provide the performance metrics for the design of optimized watermarking algorithm. In Sec. 3, we list the types of bio-inspired optimization and their abbreviations for the ease of comprehension. In Sec. 4, we perform extensive surveys with relating methods in this field in literature. And finally, we address the conclusion of this paper in Sec. 5.

2. **Some Requirements of Information Hiding.** There are many metrics to measure the effectiveness of one watermarking algorithm. From algorithm design viewpoint, the most critical three requirements are *watermark imperceptibility*, *watermark robustness*, and *watermark capacity*. Although these three requirements are all very desirable, as pointed out in literature [1, 2], they influence, or even conflict, with each other. Fixing one dimension, the remaining two have conflicts between each other, and some tradeoff must be compromised [7, 8, 9]. The interrelationships can be threefold.

1. Watermark imperceptibility refers to whether the viewer can perceive the existence of the embedded watermark or not. It implies that in Eq. (3), differences between $\boldsymbol{X}$ and $\boldsymbol{X}'$ should be as small as possible. To make the watermark imperceptible, two situations need to be considered.
   (a) The number of watermark bits embedded, or the value of N in Eq. (3), must be less than a certain threshold to make the watermark imperceptible. The increase of the value of N leads to the increase in difference values. Theoretical bound of this threshold, or the watermark capacity which is described in item 3 below, is derived in literature [10]. On the contrary, less bits embedded means less robustness of the watermarking algorithm.
   (b) Imperceptible watermarking means to modify the original media as less as possible. Besides the value of N in Eq. (3), both the embedding strength α, and the positions for watermark embedding i, play important roles for controlling the differences. The watermarked image quality is supposed to be under the just noticeable distortion (JND) region. With this point of view, in the spatial domain, the commonly employed scheme is to embed the watermark into least significant bits (LSB); in the frequency domain, embedding watermark into higher frequency band coefficients may be a feasible choice. However, by doing

so, the watermark is vulnerable to common signal processing such as low-pass filtering (LPF).

2. Watermark robustness means the capability that the watermarked media can withstand intentional or unintentional signal processing, called *attacks*. There are also benchmarks to examine the watermark robustness objectively, such as Stirmark [11]. The watermark $\boldsymbol{W}'$ should be extracted from the attacked media $\boldsymbol{X}$. Then, embedded watermark $\boldsymbol{W}$ and extracted one $\boldsymbol{W}'$ are compared. It is generally agreed that robustness plays an important role in the design of watermarking algorithm. It implies that the watermark may need to be embedded into coefficients containing larger magnitudes. By doing so, the watermarked image quality may get seriously degraded, hence others may have suspicion to the existence of the watermark. Consequently, the tradeoff between watermark imperceptibility and watermark robustness is to embed the watermark into the middle frequency bands in the transform domain.
3. Watermark capacity refers to the number of bits embedded into the original media, that is, the size of watermark. Generally speaking, if more bits can be embedded, the watermarking algorithm is supposed to be more robust; however, under such a condition, the quality of watermarked media must be degraded, hence, the existence of the watermark becomes more perceptible. Authors in [10] derived theoretical bounds for watermark capacity.

With the brief discussions above, due to the flexibilities in the design of algorithms, we may employ bio-inspired techniques for acquiring the optimized watermarking algorithms. Therefore, we need to design the appropriate fitness function at the beginning. For imperceptibility, people generally use peak signal-to-noise ratio (PSNR), structural similarity measure (SSIM) or its variants including weighted PSNR, for presenting the marked quality. For robustness, the embedded and extracted watermarks are compared, and people generally use the normalized cross-correlation (NC) or the bit-correct rate (BCR) between the two for presenting the robustness of algorithm. For capacity, the ratio between the size of watermark (in bit) and the size of media (in byte) is calculated.

Without loss of generality, we choose PSNR, BCR, and the ratio for presenting imperceptibility, robustness, and capacity, respectively. Hence, we may derive the fitness function for training by

$$f_m = \mathrm{PSNR}_m + w_1 \cdot \mathrm{BCR}_m + w_2 \cdot C_m. \tag{4}$$

Here, the subscript m denote the iteration in the training procedure. With the experiences in literature, the watermarked image quality plays an important role [12], and PSNR values are generally larger than 30 (in dB), BCR values lie between 0 and 1, and the capacity (denoted by C) is larger than 0. In order to balance the contributions from the three metrics, PSNR is the mandatory part, and the weighting factors w_1 and w_2 should be adjustable to help acquiring the optimized watermarking algorithm.

With the fundamental concepts of digital watermarking and data hiding, we are going to perform surveys for bio-inspired computing with the application to information hiding.

3. **Bio-Inspired Optimization.** With the properly designed fitness function, bio-inspired computing may be helpful to the design of watermarking algorithm. After looking for literature in the fields of information hiding researches, we have found several types of bio-inspired computing, with the abbreviations listed in alphabetical order in Table 1. Researchers make good use of these bio-inspired optimization techniques to train the flexibilities discusses in Sec. 2.

Table 1. Schemes of bio-inspired computing for information hiding.

Scheme	Abbreviation
Ant Colony Optimization	ACO
Bacterial Foraging	BF
Bee Algorithm	BA
Cat Swarm Optimization	CSO
Cuckoo Search Algorithm	CS
Differential Evolution	DE
Firefly Algorithm	FA
Genetic Algorithm	GA
Genetic Programming	GP
Particle Swarm Optimization	PSO
Simulated Annealing	SA
Tabu Search	TS

4. **Relating Methods in Literature.** We can classify the literature from two aspects. One is the media of performing watermarking, and the other is the bio-inspired computing techniques employed.

4.1. The Types of Multimedia for Information Hiding.

4.1.1. *Audio Signals.*

- In [20], authors performed watermarking on audio signals in the wavelet domain with particle swarm optimization (PSO).
- In [33], authors proposed singular-value-decomposition-based (SVD) watermarking for audio signals with differential evolution.
- In [36], authors chose genetic algorithm for accomplishing QR decomposition for audio watermarking.
- In [37, 38], authors practiced optimized watermarking on audio signals with GA.

4.1.2. *Digital Images.*

- In [13], authors proposed wavelet-based image watermarking with cuckoo search.
- In [14], authors used DCT-based SVD for watermarking with differential evolution.
- In [15], authors presented watermarking for stereoscopic images with GA.
- In [16], authors proposed image watermarking with coevolutionary GA (CGA).
- In [17, 18], authors applied reversible watermarking for using GA.
- In [19], author performed image watermarking with multi-objective bee algorithm.
- In [21, 22], authors chose watermarking on wavelet-based SVD with firefly algorithm.
- In [23], authors presented steganalysis with feature selection by using bee algorithm.
- In [24], authors experimented reversible watermarking technique in medical images with GA and PSO.
- In [25], authors performed membrane computing for image watermarking with PSO.
- In [26], authors presented the survey of watermarking on images with nature-inspired optimization, including genetic algorithm (GA), PSO, differential evolution (DE), ant colony optimization (ACO), bee algorithm (BA), cat swarm optimization (CSO), firefly algorithm (FA), and cuckoo search algorithm (CS).
- In [27], authors performed watermarking with GA-based back propagation network.
- In [28], authors proposed image hiding scheme with distortion tolerance with PSO.

- In [30], authors presented SVD-based image watermarking with hybrid training from genetic programming and PSO.
- In [31], authors proposed trusted communication of images with GA.
- In [32], the author performed watermarking by using fuzzy logic and tabu search.
- In [34] and [35], authors presented collusion resilient watermarking with GA.
- In [39], authors proposed watermarking of heterogeneous image streams with PSO.
- In [40], authors presented traces hiding in JPEG images based on tabu search.
- In [41], authors experimented reversible watermarking in integer wavelet domain for medical images with GA.
- In [42], authors designed watermarking scheme with multi-objective GA.
- In [43], the author presented watermarking on SVD-based images with tiny GA.
- In [44], authors performed wavelet-based image watermarking by using GA.
- In [45], authors proposed wavelet-based watermarking for color images with GA.
- In [46], authors presented privacy protection of medical images with both PSO and GA.
- In [47], authors presented VQ-based watermarking and error-resilient transmission with tabu search.
- In [48, 49, 50, 51], authors discussed about singular-value-decomposition-based image watermarking with tiny genetic algorithm.
- In [52], authors experimented image watermarking with multi-objective ACO.
- In [53], authors presented watermarking of bi-tonal images with dynamic particle swarm optimization (DPSO).
- In [54], authors proposed image watermarking with multi-objective GA.
- In [55], authors presented image watermarking with PSO.
- In [57], authors accomplished watermarking in fractional Fourier domain with ACO.
- In [58], authors proposed color image watermarking with PSO and k-nearest neighbor algorithm.
- In [59], authors presented robust image watermarking with bacterial foraging.
- In [60], authors proposed a framework for steganography with simulated annealing.
- In [61], authors employed BCH coding for enhanced performances in image watermarking with genetic programming.
- In [62], authors performed secure steganography methods based on GA.
- In [63], the author proposed SVD-based image watermarking with DE.
- In [64], authors presented improvements for DCT-based image watermarking with differential evolution, genetic algorithm, and particle swarm optimization.
- In [65], authors considered the robustness evaluation of image watermarking with GA.
- In [66], authors employed similarity-based robust watermarking with BF.
- In [67], authors presented fingerprinting algorithm for copyright protection with GA.
- In [68], authors proposed properly designed fitness function for image watermarking with GA.
- In [69] and [70], authors employed SVD-based image watermarking with micro-GA.
- In [71], authors presented the optimal detection of watermark in images with GA.
- In [72], the author proposed SVD-based image watermarking with GA.
- In [73], authors employed zerotree wavelet for image watermarking with GA.
- In [74], authors proposed access control schemes on watermarked scalable media, including images and video, with GA.
- In [75], authors presented progressive transmission of watermarked image with GA.
- In [76], authors considered intelligent shaping of a digital watermark using GP.
- In [77], authors proposed a steganographic method for JPEG by using PSO.

- In [78, 79], authors presented the codebook partition for VQ-based watermarking with GA.
- In [80], authors took discrete multiwavelet transform for watermarking with GA.
- In [81], authors considered using watermarking and compression for medical images based on GA.
- In [82], authors presented the enhancement of watermark retrieval with GA.
- In [83], authors optimized the transmission of VQ-based watermarked images with GA.
- In [84] and [85], authors proposed DCT-based image watermarking for the selection of embedding positions with GA.
- In [86], authors proposed DCT-based image watermarking for the selection of embedding positions with tabu search.
- In [87], authors presented image-based multiple watermarking in VQ and DCT domains with GA.

4.1.3. *Video.*

- In [56], authors proposed H.264/AVC-based video watermarking with PSO.
- In [74], authors proposed access control schemes on watermarked scalable media, including images and video, with GA.

4.1.4. *Vital Signs.*

- In [29], authors performed watermarking on electrocardiogram (ECG) signal by using cuckoo search.

4.2. **The Types of Bio-Inspired Optimization Techniques for Watermarking.** We list the types of bio-inspired optimization techniques in alphabetical order in this Section.

4.2.1. *Ant Colony Optimization.*

- In [26], authors surveyed nature-inspired optimization, including ACO, for watermarking digital images.
- In [52], authors chose ACO for experimenting image watermarking.
- In [57], authors used ACO for image-based watermarking in fractional Fourier domain.

4.2.2. *Bacterial Foraging.*

- In [59], authors employed bacterial foraging for image watermarking.
- In [66], authors chose bacterial foraging for designing similarity-based robust watermarking.

4.2.3. *Bee Algorithm.*

- In [19], author performed image watermarking with multi-objective bee algorithm.
- In [23], authors experimented the use of bee algorithm for image steganalysis with feature selection.
- In [26], authors surveyed nature-inspired optimization, including BA, for watermarking digital images.

4.2.4. *Cat Swarm Optimization.*

- In [26], authors surveyed nature-inspired optimization, including CSO, for watermarking digital images.

4.2.5. *Cuckoo Search Algorithm.*

- In [13], authors chose cuckoo search for wavelet-based image watermarking.
- In [26], authors surveyed nature-inspired optimization, including cuckoo search algorithm, for watermarking digital images.
- In [29], authors practiced cuckoo search for watermarking on electrocardiogram (ECG) signal.

4.2.6. *Differential Evolution.*

- In [26], authors surveyed nature-inspired optimization, including differential evolution, for watermarking digital images.
- In [14], authors employed DE for watermarking with DCT-based SVD.
- In [33], authors proposed DE for watermarking SVD-based audio signals.
- In [63], the author chose DE for SVD-based robust watermarking for images.
- In [64], authors employed using intelligent optimization, including differential evolution, for presenting improvements in DCT-based image watermarking.

4.2.7. *Firefly Algorithm.*

- In [21] and [22], authors performed watermarking on wavelet-based SVD with firefly algorithm.
- In [26], authors surveyed nature-inspired optimization, including FA, for watermarking digital images.

4.2.8. *Genetic Algorithm.*

- In [15], authors used GA for watermarking stereoscopic images.
- In [16], authors proposed using coevolutionary GA (CGA) for image watermarking.
- In [17, 18], authors chose GA for applications to reversible watermarking.
- In [24], authors employed GA and PSO for reversible watermarking technique in medical images.
- In [26], authors surveyed nature-inspired optimization, including GA, for watermarking digital images.
- In [27], authors chose accomplished GA-based back propagation network for embedding watermark into images.
- In [30], authors presented hybrid training with genetic programming and PSO for SVD-based image watermarking.
- In [31], authors proposed using GA for trusted communication of images.
- In [37] and [38], authors employed GA to practice optimized watermarking on audio signals.
- In [34] and [35], authors chose GA for collusion resilient watermarking on images.
- In [41], authors used GA for reversible watermarking of medical images.
- In [42], authors employed multi-objective GA for designing watermarking scheme.
- In [43], the author presented tiny GA for watermarking on SVD-based images.
- In [44], authors employed GA for wavelet-based image watermarking.
- In [45], authors proposed using GA for wavelet-based watermarking with applications to color images.
- In [46], authors employed both PSO and GA for protecting patients' privacy of medical images.
- In [48, 49, 50, 51], authors discussed about the use of tiny genetic algorithm for singular-value-decomposition-based image watermarking.
- In [54], authors proposed multi-objective genetic algorithm for image watermarking.

- In [61], authors chose genetic programming for integrating BCH coding with enhanced performances in image watermarking.
- In [62], authors chose GA for optimizing secure steganography.
- In [64], authors employed using intelligent optimization, including genetic algorithm, for presenting improvements in DCT-based image watermarking.
- In [65], authors considered using GA for enhancing the robustness evaluation of image watermarking algorithm.
- In [67], authors employed GA for presenting fingerprinting algorithm.
- In [68], authors proposed using properly designed fitness function in GA for optimized watermarking.
- In [69] and [70], authors employed micro-GA for SVD-based image watermarking.
- In [71], authors chose GA for training the optimal detection of watermark in images.
- In [72], the author employed GA for SVD-based image watermarking.
- In [73], authors employed GA for zerotree-wavelet-based image watermarking.
- In [74], authors considered GA for optimizing access control schemes on watermarked scalable images and video.
- In [75], authors chose GA for progressive transmission of watermarked images.
- In [76], authors employed genetic programming for intelligent shaping of a digital watermark.
- In [78, 79], authors presented the use of GA for VQ-based watermarking.
- In [80], authors chose GA for optimizing discrete multiwavelet transform for image watermarking.
- In [81], authors proposed the use og GA for watermarking and compression in medical images.
- In [82], authors employed GA for the enhancement of watermark retrieval.
- In [83], authors took GA for optimizing the transmission of VQ-based watermarked images.
- In [84] and [85], authors employed GA for choosing appropriate embedding positions for DCT-based image watermarking.
- In [87], authors chose GA for image-based multiple watermarking in VQ and DCT domains.

4.2.9. *Particle Swarm Optimization.*

- In [20], authors employed PSO for watermarking audio signals in the wavelet domain.
- In [24], authors chose GA and PSO for reversible watermarking technique in medical images.
- In [25], authors used PSO with membrane computing for watermarking on images.
- In [26], authors surveyed nature-inspired optimization, including PSO, for watermarking digital images.
- In [28], authors proposed using PSO for image hiding with distortion tolerance.
- In [30], authors presented hybrid training with genetic programming and PSO for SVD-based image watermarking.
- In [39], authors chose PSO for watermarking heterogeneous image streams.
- In [46], authors employed both PSO and GA for protecting patients' privacy of medical images.
- In [53], authors took dynamic particle swarm optimization (DPSO) for training watermarking of bi-tonal images.
- In [55], authors employed PSO for image watermarking.
- In [56], authors used PSO for watermarking H.264/AVC-compressed video.

- In [58], authors proposed the use of PSO and k-nearest neighbor algorithm for color image watermarking.
- In [64], authors employed using intelligent optimization, including particle swarm optimization, for presenting improvements in DCT-based image watermarking.
- In [77], authors presented the use of PSO for JPEG-based steganography.

4.2.10. *Simulated Annealing.*

- In [60], authors employed simulated annealing and proposed a framework for image steganography.

4.2.11. *Tabu Search.*

- In [32], the author took tabu search and fuzzy logic for watermarking images.
- In [40], authors presented the use of tabu search for hiding traces in JPEG images.
- In [47], authors employed tabu search for watermarking and error-resilient transmission on images.
- In [86], authors chose tabu search for choosing appropriate embedding positions for DCT-based image watermarking.

5. **Conclusions.** In this paper, we presented extensive reviews for bio-inspired information hiding techniques in literature. The design methodology of deriving the fitness functions, the optimization techniques employed, and the types of multimedia for applications, are all addressed. From the surveys performed, we observe that researchers focus the type of multimedia on digital images for most of the cases in Sec. 4.1. In addition, even though 11 different kinds of bio-inspired optimization techniques and/or their variants can be observed in Sec. 4.2, around half amount of the papers we searched for focus on genetic algorithm. With the algorithm developed, papers published recently may turn to relating methods in bio-inspired optimization, for instance, swarm intelligence. With the surveys presented, we would like to bring some insights to the new trends in this field.

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REFERENCES

[1] J. S. Pan, H. C. Huang, L. C. Jain, and Y. Zhao, *Recent Advances in Information Hiding and Applications*, Springer, 2012.
[2] J. S. Pan, H. C. Huang, and L. C. Jain, *Information Hiding and Applications*, Springer, 2009.
[3] A. Z. Tirkel, G. A. Rankin, R. M. van Schyndel, W. J. Ho, N. R. A. Mee, and C. F. Osborne, Electronic water mark, *Proc. Digital Image Computing Techniques and Applications '93*, pp. 666–672, 1993
[4] C. De Vleeschouwer, J. F. Delaigle, and B. Macq, Invisibility and application functionalities in perceptual watermarking — An overview, *Proc. of the IEEE*, vol. 90, no. 1, pp. 64–77, Jan. 2002
[5] Y. H. Chen and H. C. Huang, The copyright protection system for Android platform, *Recent Advances in Information Hiding and Applications*, Chapter 2, pp. 19–32, 2012.
[6] Z. Liu, H. C. Huang, and J. S. Pan, Digital watermarking – Backgrounds, techniques, and industrial applications, *Communications of the CCISA*, vol. 10, no. 1, pp. 44–63, Jan. 2004.
[7] H. C. Huang and W.C. Fang, Metadata-based image watermarking for copyright protection, *Simulation Modelling Practice and Theory*, vol. 18, no. 4, pp. 436–445, Apr. 2010.
[8] F. H. Wang, L. C. Jain, J. S. Pan, and H. C. Huang, Digital image watermarking approach based on lapped orthogonal transform, *Proc. IEEE APCCAS*, pp. 1133–1136, 2004.
[9] S. Moskowitz, What is acceptable quality in the application of digital watermarking: Trade-offs of security, robustness and quality, *Proc. Int'l Conf. Info. Tech.: Coding and Comp.*, pp. 80–84, 2002.
[10] C. Y. Lin and S. F. Chang, Watermarking capacity of digital images based on domain-specific masking effects, *Proc. Int'l Conf. Info. Tech.: Coding and Comp.*, pp. 90–94, 2001.

[11] F. A. P. Petitcolas, Watermarking schemes evaluation, *IEEE Signal Processing Magazine*, vol. 17, no. 5, pp. 58–64, Sep. 2000.

[12] Y. H. Chen and H. C. Huang, Adaptive image watermarking optimized for pre-specified fidelity, *Proc. Int'l Conf. on Innovative Computing, Information and Control*, pp. 1305–1308, 2009.

[13] M. Ali and C.W. Ahn, An optimal image watermarking approach through cuckoo search algorithm in wavelet domain, *Int'l Journal of System Assurance Engineering and Management* (Online available, Aug. 2014) (DOI: 10.1007/s13198-014-0288-4)

[14] M. Ali, C. W. Ahn, and M. Pant, A robust image watermarking technique using SVD and differential evolution in DCT domain, *Optik*, vol. 125, no. 1, pp. 428–434, 2014.

[15] Y.H. Chen and H.C. Huang, A wavelet-based genetic watermarking scheme for stereoscopic images", *Proc. IEEE ICCE-Taiwan*, pp. 113–114, 2014.

[16] Y.H. Chen and H.C. Huang, Coevolutionary genetic watermarking for owner identification, *Neural Computing and Applications* (Online available, May 2014) (DOI: 10.1007/s00521-014-1615-z)

[17] Y.H. Chen and H.C. Huang, Reversible image watermarking based on genetic algorithm, *Proc. Int'l Conf. on IIHMSP*, pp. 21–24, 2014.

[18] H. C. Huang, T. H. Wang, Y. H. Chen, and J. P. Hung, Prediction-based reversible data hiding for medical images with genetic algorithms, *Proc. Int'l Conf. on IIHMSP*, pp. 5–8, 2013.

[19] J. S. Lee, J. W. Wang, and K. Y. Giang, A new image watermarking scheme using multi-objective bees algorithm, *Applied Math. & Information Sciences*, vol. 8, no. 6, pp. 2945–2953, Nov. 2014.

[20] B. Lei, F. Zhou, E. L. Tan, D. Ni, H. Lei, S Chen, and T. Wang, Optimal and secure audio watermarking scheme based on self-adaptive particle swarm optimization and quaternion wavelet transform, *Signal Processing* (Online available, Dec. 2014) (DOI: 10.1016/j.sigpro.2014.11.007)

[21] A. Mishra, C. Agarwal, A. Sharma, and P. Bedi, Optimized gray-scale image watermarking using DWT-SVD and firefly algorithm, *Expert Sys. with App.*, vol. 41, no. 17, pp. 7858–7867, Dec. 2014.

[22] M. Ali and C. W. Ahn, Comments on 'Optimized gray-scale image watermarking using DWT-SVD and firefly algorithm', *Expert Sys. with App.*, vol. 42, no. 5, pp. 2392–2394, Apr. 2015.

[23] F.G. Mohammadi and M.S. Abadeh, Image steganalysis using a bee colony based feature selection algorithm, *Engineering Applications of Artificial Intelligence*, vol. 31, pp. 35–43, May 2014.

[24] T. Naheed, I. Usman, T. M. Khan, A. H. Dar, and M.F. Shafique, Intelligent reversible watermarking technique in medical images using GA and PSO, *Optik*, vol. 125, no. 11, pp. 2515–2525, Jun. 2014.

[25] H. Peng, J. Wang, Mario J. Pérez-Jiménez, and A. Riscos-Núñez, The framework of P systems applied to solve optimal watermarking problem, *Signal Proc.*, vol. 101, pp. 256–265, Aug. 2014.

[26] J. Waleed, H.D. Jun, T. Abbas, S. Hameed, and H. Hatem, A survey of digital image watermarking optimization based on nature inspired algorithms, *International Journal of Security and Its Applications*, vol. 8, no. 6, pp. 315–334, Nov. 2014.

[27] C. Agarwal, A. Mishra, and A. Sharma, Gray-scale image watermarking using GA-BPN hybrid network, *J. Visual Commun. Image Repre.*, vol. 24, no. 7, pp. 1135–1146, Oct. 2013.

[28] P. Bedi, R. Bansal, and P. Sehgal, Using PSO in a spatial domain based image hiding scheme with distortion tolerance, *Computers & Electrical Engineering*, vol. 39, no. 2, pp. 640–654, Feb. 2013.

[29] N. Dey, S. Samanta, X. S. Yang, A. Das, and S. S. Chaudhuri, Optimisation of scaling factors in electrocardiogram signal watermarking using cuckoo search, *International Journal of Bio-Inspired Computation*, vol. 5, no. 5, pp. 315–326, Oct. 2013.

[30] F. Golshan and K. Mohammadi, A hybrid intelligent SVD-based perceptual shaping of a digital image watermark in DCT and DWT domain, *The Imaging Science Journal*, vol. 61, no. 1, pp. 35–46, Jan. 2013.

[31] H. C. Huang and Y. H. Chen, Application of genetic-based wavelet packet watermarking for trusted communication, *Information*, vol. 16, no. 1(A), pp. 295–306, Jan. 2013.

[32] A. Latif, An adaptive digital image watermarking scheme using fuzzy logic and tabu search, *Journal of Inform. Hiding and Multimedia Signal Processing*, vol. 4, no. 4, pp. 250–271, Oct. 2013.

[33] B. Lei, I. Y. Soon, and E. L. Tan, Robust SVD-based audio watermarking scheme with differential evolution optimization, *IEEE Trans. Audio, Speech, and Language Processing*, vol. 21, no. 11, pp. 2368–2378, Nov. 2013.

[34] S. P. Maity, S. Maity, J. Sil, and C. Delpha, Collusion resilient spread spectrum watermarking in M-band wavelets using GA-fuzzy hybridization, *J. Syst. Soft.*, vol. 86, no. 1, pp. 47–59, Jan. 2013.

[35] Y. H. Chen and H. C. Huang, Collusion-resilient fingerprinting using cropping and subsampling, *Proc. Fifth Int'l Conf. on Information Assurance and Security*, pp. 98–101, 2009.

[36] S. M. Mohsenfar, M. Mosleh, and A. Barati, Audio watermarking method using QR decomposition and genetic algorithm, *Multi. Tools and App.* (Online, Sep. 2013) (DOI: 10.1007/s11042-013-1694-3)

[37] H. Peng, J. Wang, and Z. Zhang, Audio watermarking scheme robust against desynchronization attacks based on kernel clustering, *Multi. Tools and App.*, vol. 62, no. 3, pp. 681–699, Feb. 2013.

[38] H. Peng and J. Wang, Optimal audio watermarking scheme using genetic optimization, *Annals of Telecommunications*, vol. 66, no. 5-6, pp. 307–318, Jun. 2011.

[39] E. Vellasques, R. Sabourin, and E. Granger, Fast intelligent watermarking of heterogeneous image streams through mixture modeling of PSO populations, *Applied Soft Computing*, vol. 13, no. 6, pp. 3130–3148, Jun. 2013.

[40] S. Wang and X. M. Niu, Hiding traces of double compression in JPEG images based on tabu search, *Neural Computing and Applications*, vol. 22, no. 1, pp. 283–291, May 2013.

[41] M. Arsalan, S.A. Malik, and A. Khan, Intelligent reversible watermarking in integer wavelet domain for medical images, *Journal of Systems and Software*, vol. 85, no. 4, pp. 883–894, Apr. 2012.

[42] Y. H. Chen and H. C. Huang, Robust image watermarking using coevolutionary multi-objective evolutionary algorithm, *Proc. Int'l Conf. on IIHMSP*, pp. 238–241, 2012.

[43] K. Loukhaoukha, On the security of digital watermarking scheme based on singular value decomposition and tiny genetic algorithm, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 3, no. 2, pp. 135–141, Apr. 2012.

[44] K. Ramanjaneyulu and K. Rajarajeswari, Wavelet-based oblivious image watermarking scheme using genetic algorithm, *IET Image Processing*, vol. 6, no. 4, pp. 364–373, Jun. 2012.

[45] E. Vahedi, R. A. Zoroofi, and M. Shiva, Toward a new wavelet-based watermarking approach for color images using bio-inspired optimization principles, *Digital Signal Processing*, vol. 22, no. 1, pp. 153–162, Jan. 2012.

[46] P. Fakhari, E. Vahedi, C. Lucas, Protecting patient privacy from unauthorized release of medical images using a bio-inspired wavelet-based watermarking approach, *Digital Signal Processing*, vol. 21, no. 3, pp. 433–446, May 2011.

[47] H. C. Huang, S. C. Chu, J. S. Pan, C. Y. Huang, and B. Y. Liao, Tabu search based multi-watermarks embedding algorithm with multiple description coding, *Information Sciences*, vol. 181, no. 16, pp. 3379–3396, Aug. 2011.

[48] C. C. Lai, A digital watermarking scheme based on singular value decomposition and tiny genetic algorithm, *Digital Signal Processing*, vol. 21, no. 4, pp. 522–527, Jul. 2011.

[49] K. Loukhaoukha, Comments on 'A digital watermarking scheme based on singular value decomposition and tiny genetic algorithm', *Digital Signal Processing*, vol. 23, no. 4, pp. 1334, Jul. 2013.

[50] E. Yavuz and Z. Telatar, Comments on 'A digital watermarking scheme based on singular value decomposition and tiny genetic algorithm', *Dig. Sig. Proc.*, vol. 23, no. 4, pp. 1335–1336, Jul. 2013.

[51] C. C. Lai, Corrigendum to 'A digital watermarking scheme based on singular value decomposition and tiny genetic algorithm', *Digital Signal Processing*, vol. 23, no. 4, pp. 1333, Jul. 2013.

[52] K. Loukhaoukha, J. Y. Chouinard, and M. H. Taieb, Optimal image watermarking algorithm based on LWT-SVD via multi-objective ant colony optimization, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 2, no. 4, pp. 303–319, Oct. 2011.

[53] E. Vellasques, R. Sabourin, and E. Granger, A high throughput system for intelligent watermarking of bi-tonal images, *Applied Soft Computing*, vol. 11, no. 8, pp. 5215–5229, Dec. 2011.

[54] J. Wang, H. Peng, and P. Shi, An optimal image watermarking approach based on a multi-objective genetic algorithm, *Information Sciences*, vol. 181, no. 24, pp. 5501–5514, Dec. 2011.

[55] Y. R. Wang, W. H. Lin, and L. Yang, An intelligent watermarking method based on particle swarm optimization, *Expert Systems with Applications*, vol. 38, no. 7, pp. 8024–8029, Jul. 2011.

[56] C. H. Wu, Y. Zheng, W. H. Ip, C. Y. Chan, K. L. Yung, and Z. M. Lu, A flexible H.264/AVC compressed video watermarking scheme using particle swarm optimization based dither modulation, *AEU – Int'l Journal of Electronics and Communications*, vol. 65, no. 1, pp. 27–36, Jan. 2011.

[57] H. Al-Qaheri, A. Mustafi, and S. Banerjee, Digital watermarking using ant colony optimization in fractional Fourier domain, *J. Inform. Hid. Multi. Signal Proc.*, vol. 1, no. 3, pp. 179–189, Jul. 2010.

[58] O. Fındık, Ī. Babaoğlu, and E. Ülker, A color image watermarking scheme based on hybrid classification method: Particle swarm optimization and k-nearest neighbor algorithm," *Optics Communications*, vol. 283, no. 24, pp. 4916–4922, Dec. 2010,

[59] H. C. Huang, Y. H. Chen, and A. Abraham, Optimized watermarking using swarm-based bacterial foraging, *J. of Inform. Hiding and Multimedia Signal Processing*, vol. 1, no. 1, pp. 51–58, Jan. 2010.

[60] T. C. I. Lin, Y. T. Chang, and W. N. Lie, A framework of enhancing image steganography with picture quality optimization and anti-steganalysis based on simulated annealing algorithm, *IEEE Trans. Multimedia*, vol. 12, no. 5, pp. 345–357, May 2010.

[61] I. Usman and A. Khan, BCH coding and intelligent watermark embedding: Employing both frequency and strength selection, *Applied Soft Computing*, vol. 10, no. 1, pp. 332–343, Jan. 2010.
[62] S. Wang, B. Yang, and X.M. Niu, A secure steganography method based on genetic algorithm, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 1, no. 1, pp. 28–35, Jan. 2010.
[63] V. Aslantas, An optimal robust digital image watermarking based on SVD using differential evolution algorithm, *Optics Communications*, vol. 282, no. 5, pp. 769–777, Mar. 2009.
[64] V. Aslantas, S. Ozer, and S. Ozturk, Improving the performance of DCT-based fragile watermarking using intelligent optimization algorithms, *Opt. Commun.*, vol. 282, no. 14, pp. 2806–2817, Jul. 2009.
[65] G. Boato, V. Conotter, F.G.B. De Natale, and C. Fontanari, Watermarking robustness evaluation based on perceptual quality via genetic algorithms, *IEEE Trans. Information Forensics and Security*, vol. 4, no. 2, pp. 207–216, Jun. 2009.
[66] H. C. Huang and F. C. Chang, Similarity-based watermarking for sub-sampling images with bacterial foraging techniques, *Proc. Int'l Conf. on IIHMSP*, pp. 836–839, 2009.
[67] H. C. Huang and Y. H. Chen, Genetic fingerprinting for copyright protection of multicast media, *Soft Computing*, vol. 13, no. 4, pp. 383–391, Feb. 2009.
[68] H. C. Huang, C. M. Chu, and J. S. Pan, The optimized copyright protection system with genetic watermarking, *Soft Computing*, vol. 13, no. 4, pp. 333–343, Feb. 2009.
[69] C.C. Lai, H.C. Huang, and C.C. Tsai, A digital watermarking scheme based on singular value decomposition and micro-genetic algorithm, *Int'l Journal of Innovative Computing, Information and Control*, vol. 5, no. 7, pp. 1867–1873, Jul. 2009.
[70] C. C. Lai, H. C. Huang and C. C. Tsai, Image watermarking scheme using singular value decomposition and micro-genetic algorithm, *Proc. Int'l Conf. on IIHMSP*, pp. 469–472, 2008.
[71] S. P. Maity and M. K. Kundu, Genetic algorithms for optimality of data hiding in digital images, *Soft Computing*, vol. 13, no. 4, pp. 361–373, Feb. 2009.
[72] V. Aslantas, A singular-value decomposition-based image watermarking using genetic algorithm, *AEU – Int'l Journal of Electronics and Communications*, vol. 62, no. 5, pp. 386–394, May 2008.
[73] S. C. Chu, H. C. Huang, Y. Shi, S. Y. Wu, and C. S. Shieh, Genetic watermarking for zerotree-based applications, *Circuits, Systems, and Signal Processing*, vol. 27, no. 2, pp. 171–182, Apr. 2008.
[74] F. C. Chang, H. C. Huang, and H. M. Hang, Layered access control schemes on watermarked scalable media, *Journal of VLSI Signal Processing Systems for Signal, Image, and Video Technology*, vol. 49, no. 3, pp. 443–455, Dec. 2007.
[75] H. C. Huang, J. S. Pan, Y. Huang, F. Wang, and K. C. Huang, Progressive watermarking techniques using genetic algorithms, *Circuits Syst. Signal Process.*, vol. 26, no. 5, pp. 671–687, Oct. 2007.
[76] A. Khan and A. M. Mirza, Genetic perceptual shaping: Utilizing cover image and conceivable attack information during watermark embedding, *Information Fusion*, vol. 8, no. 4, pp. 354–365, Oct. 2007.
[77] X. Li and J. Wang, A steganographic method based upon JPEG and particle swarm optimization algorithm, *Information Sciences*, vol. 177, no. 15, pp. 3099–3109, Aug. 2007.
[78] F. H. Wang, L. C. Jain, and J. S. Pan, VQ-based watermarking scheme with genetic codebook partition, *Journal of Network and Computer Applications*, vol. 30, no. 1, pp. 4–23, Jan. 2007.
[79] F. H. Wang, J. S. Pan, L. C. Jain, and H. C. Huang, VQ-based gray watermark hiding scheme and genetic index assignment, *Proc. IEEE PCM*, pp. 73–80, 2004.
[80] P. Kumsawat, K. Attakitmongcol, and A. Srikaew, A new approach for optimization in image watermarking by using genetic algorithms, *IEEE Trans. Signal Processing*, vol. 53, no. 12, pp. 4707–4719, Dec. 2005.
[81] F. Y. Shih and Y. T. Wu, Robust watermarking and compression for medical images based on genetic algorithms, Information Sciences, vol. 175, no. 3, pp. 200–216, Oct. 2005.
[82] F. Y. Shih and Y. T. Wu, Enhancement of image watermark retrieval based on genetic algorithms, *J. Visual Commun. Image Repre.*, vol. 16, no. 2, pp. 115–133, Apr. 2005.
[83] J. S. Pan, M. T. Sung, H. C. Huang, and B. Y. Liao, Robust VQ-based digital watermarking for the memoryless binary symmetric channel, *IEICE Trans. Fundamentals*, vol. E-87A, pp. 1839–1841, Jul. 2004.
[84] C. S. Shieh, H. C. Huang, F. H. Wang, and J. S. Pan, Genetic watermarking based on transform-domain techniques, *Pattern Recognition*, vol. 37, no. 3, pp. 555–565, Mar. 2004.
[85] J. S. Pan, H. C. Huang, and F. H. Wang, Genetic watermarking techniques, *Int'l Conf. Knowledge-Based Intelligent Inform. Engineering System & Allied Technologies*, pp. 1032–1036, 2001.
[86] H. C. Huang, J. S. Pan, F. H. Wang, and C. S. Shieh, Robust image watermarking with tabu search approaches, *Proc. IEEE Int'l Symp. on Consumer Electronics 2003*, paper no.: ISCE03010, 2003.

[87] C. S. Shieh, H. C. Huang, F. H. Wang, and J. S. Pan, An embedding algorithm for multiple watermarks, *Journal of Information Science and Engineering*, vol. 19, no. 2, pp. 381-395, Mar. 2003.