

# An Image Watermarking Algorithm in DCT Domain Based on Optimal Patterns

Anna Melman

*Dep. of Information Security of Cyber-Physical Systems  
HSE University  
Moscow, Russia  
amelman@hse.ru*

Oleg Evsutin

*Dep. of Information Security of Cyber-Physical Systems  
HSE University  
Moscow, Russia  
oevsyutin@hse.ru*

Danil Smirnov

*Dep. of Information Security of Cyber-Physical Systems  
HSE University  
Moscow, Russia  
dvsmirnov@hse.ru*

**Abstract**— Sharing images via social media and specialized sites creates a copyright issue. Image watermarking methods provide copyright protection for authors and owners of digital content. The security level of a watermarking algorithm depends on a watermark's resistance to various distorting effects, such as brightness changing, contrast changing, applying a Gaussian filter, and others. At the same time, a watermark needs to be invisible in most cases, so as not to disturb a perception of an image by a viewer. In this paper, we propose a new image watermarking algorithm in a domain of discrete cosine transform, which provides a balance between embedding imperceptibility and robustness. This algorithm uses redundant embedding based on patterns and synchronization blocks to provide embedding robustness to image processing operations. A high level of imperceptibility is provided by optimizing patterns using a genetic algorithm. Experimental results demonstrate high values of key quality metrics such as PSNR, SSIM, and BER.

**Keywords**— watermarking, image processing, discrete cosine transform, genetic algorithm

## I. INTRODUCTION

The Internet enables digital content creators to quickly and conveniently distribute the results of their work. Authors of digital images, such as photographs and illustrations, actively use social networks and specialized sites to demonstrate their creative progress, find like-minded people or clients. However, publishing any digital content online makes it vulnerable to attackers. An attacker can copy an image and then illegally modify or distribute it. Authors and rightful owners of images need to use special protection measures, in particular image watermarking tools, to protect copyright of images.

Watermarking methods embed additional data into images that can be used to authenticate authors or owners. Such data can be other images, such as logos, or multi-component identifiers, including information about creation of images and their content. Watermarking schemes used in practice are divided into visible and invisible ones. Visible schemes embed a watermark in such a way that the fact of its presence in an image is obvious to a viewer. Such schemes directly prevent illegal distribution of digital content. Invisible schemes embed watermarks into images in an invisible way. Their useful effect is usually disclosed if the fact of illegal distribution of content is discovered. In this case, the presence of a watermark in some image copy serves as proof of copyright of a rightful owner or author. In this study, we focus on invisible watermarking techniques.

---

This work is an output of a research project implemented as part of the Basic Research Program at the National Research University Higher School of Economics (HSE University).

An efficient invisible watermarking scheme ensures the high quality of watermarked images and resistance to accidental or intentional distortions of watermarked images. In other words, the embedding algorithm should demonstrate high rates of embedding imperceptibility and robustness. In most cases, these performance indicators of watermarking schemes conflict with each other, and improving values of one of them leads to a deterioration in other one. Therefore, this paper proposes a new algorithm for invisible watermarking, which is distinguished by a high level of invisibility and embedding resistance to various image processing operations due to embedding redundancy and the use of metaheuristic optimization.

## II. RELATED WORK

Image watermarking is a promising method for protecting digital content, and a large number of algorithms have been published by various authors. Some watermarking algorithms operate in a spatial domain and change image pixels during an embedding stage [1, 2]. Other watermarking schemes work with frequency transform coefficients such as discrete cosine transform (DCT) coefficients, discrete wavelet transform (DWT) coefficients, and Fourier transform ones [3, 4]. In general, watermark embedding into the frequency domain provides a higher level of robustness.

Achieving a high level of embedding imperceptibility and robustness within a watermarking scheme is challenging. Some researchers consider this problem as an optimization problem and use popular metaheuristics such as genetic algorithm (GA), particle swarm optimization (PSO) and others to strike a balance between the key performance indicators of watermarking schemes. The use of metaheuristic optimization in watermarking schemes is most often aimed at choosing the best embedding strength parameter [5]. For example, in [6], the authors use PSO to find the embedding strength in a DCT domain based watermarking algorithm designed for multi-spectral images. Image blocks are selected according to an entropy criterion for embedding watermark bits, and predicted values of DCT coefficients are involved in an embedding procedure. In [7], an embedding scheme based on DCT, DWT, and neural networks uses two robustness modules: the first module improves resistance to geometric distortions, and the second one improves resistance to other distortions. The authors use GA to find the embedding strength coefficient.

Less popular metaheuristics are also used by various authors to search for parameters of embedding algorithms. For example, to improve efficiency of watermark embedding in the DCT domain, in [8], the authors use teaching-learning-based optimization (TLBO), and Harris hawks optimization (HHO) algorithm is used in [9].

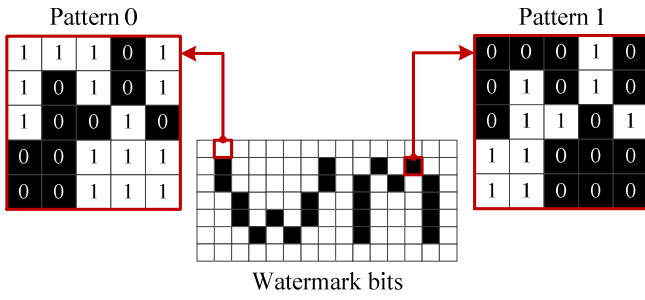


Fig. 1. Pattern examples.

One can also note watermark bit arrangement selection [10, 11] among other tasks for which authors of watermarking schemes use metaheuristic optimization [5]. Other tasks, such as extraction parameter selection [12, 13], are much less common.

Thus, the following can be noted. Despite the fact that the use of metaheuristic optimization is quite widespread in the field of image watermarking, optimization problems other than choosing the best embedding parameters are rarely described in the scientific literature. Therefore, the choice of optimal embedding patterns using metaheuristic optimization, in particular, GA, is an original approach to improving the information embedding efficiency.

### III. PROPOSED APPROACHES

In this paper, we propose a new watermarking algorithm for images. The increase in robustness is achieved by increasing the redundancy of embedding by using additional sequences to encode watermark bits, which we call embedding patterns. The problem of maintaining a balance between imperceptibility of embedding and robustness is solved by applying a GA at the stage of pattern generating. In this section, we describe the proposed approach in detail.

#### A. Embedding Patterns

In this study, a watermark is considered as a binary sequence. Embedding patterns are also binary sequences and are used to encode a watermark at an embedding stage. A pattern 0 is used to encode 0 bit, and its inverted version, a pattern 1, is used to encode 1 bit. Fig. 1 shows an example of pattern 0 and its corresponding pattern 1. Patterns in Fig. 1 have a size of 25 bits, but a size of patterns may vary in practice.

An embedding method is a quantization index modulation (QIM) [14] method, which consists in modulating values of image data elements (pixels or frequency coefficients). In this work, we implement the QIM method in DCT domain, since embedding information into the spatial domain of images is generally less resistant to image processing operations. An original image is divided into non-overlapping  $8 \times 8$  pixel blocks before embedding, and 2D DCT is applied to them. Middle frequency DCT coefficients are the most suitable for embedding additional information, since they provide a compromise between embedding imperceptibility and robustness [15]. Thus, pattern embedding is performed into mid-frequency coefficients of DCT coefficient blocks. If a watermark bit is 0, pattern 0 is applied to a block of DCT coefficients. If a watermark bit is 1, then pattern 1 is applied to a block. In this case, modification of a coefficient  $c$  using a pattern bit  $p$  is carried out in accordance with the following equation [16]:

$$c_p = \text{sign } c \cdot \left( q \cdot \left\lfloor \frac{|c|}{q} \right\rfloor + \frac{q}{2} \cdot p \right), \quad (1)$$

where  $c_p$  is a DCT coefficient after embedding, and  $q$  is a quantization step.

At the extraction stage, a pattern bit  $p'$  is determined by a watermarked coefficient  $c'$  according to the following formula:

$$p' = \arg \min_{l \in [0,1]} |c' - c_l|. \quad (2)$$

As a result of the extraction procedure, separate sequences are obtained, each of which corresponds to 0 or 1 bit value of an extracted watermark. However, in this case, there is an extraction ambiguity. The proposed scheme uses blind extraction. This means that user has no information about an original watermark and patterns at the extraction stage. The user does not know which pattern corresponds to 0 bit and which one corresponds to 1 bit. There are two options for interpreting the extracted sequences and, therefore, two options for the extracted watermark, one of which is an inverted version of the other. We use a part of image blocks for synchronization purposes to solve this problem. Such blocks do not contain watermark bits and are called synchronization blocks. The same pattern 0 is embedded in all synchronization blocks. In the extraction phase, patterns are first extracted from all synchronization blocks, and each bit of the pattern is determined by the simple majority principle. The remaining blocks contain embedded patterns corresponding to watermark bits, and the decision on the value of a particular watermark bit  $b$  is made as follows:

$$b = \begin{cases} 0, & \text{if } Diff < 0.5 \\ 1, & \text{otherwise} \end{cases}, \quad (3)$$

where

$$Diff = \frac{1}{K} \sum_{i=1}^K |p_i^0 - p_i^{cur}|, \quad (4)$$

$p_i^{cur}$  is a pattern bit extracted from current block,  $p_i^0$  is a bit of pattern 0 obtained with synchronization blocks, and  $K$  is a number of pattern bits.

The proposed approach makes it possible to increase the robustness of embedding by increasing redundancy. However, an increase in redundancy means an increase in the total embedding capacity, i.e. amount of embedded information. This negatively affects the imperceptibility of embedding. We propose to use metaheuristic optimization, in particular, GA, to solve this problem and strike a balance between imperceptibility and robustness.

#### B. Genetic Algorithm

GA [17] is a popular metaheuristic optimization algorithm inspired by evolutionary processes in nature. GA considers each possible solution to a problem as an individual of a population or a chromosome, and each

individual variable as a chromosome's gene. The quality of each decision is interpreted as the fitness of the individual and is evaluated using a fitness function. During an optimization process, crossover and mutation operators are applied to the population with some predetermined probabilities. As a result of the crossover operator, two chromosomes exchange one or several fragments. The mutation operator performs a change in one or several randomly selected genes on descendant chromosomes. Next, the fitness function values are evaluated, and individuals with the best fitness form an updated population. After optimization is complete, the individual with the best fitness value becomes the solution to the problem.

GA is a classic well known algorithm and it is often used to solve optimization problems in digital image watermarking schemes [5, 18]. Classical GA is well suited for problems where solutions are vectors of binary or integer values. This study proposes to use GA to select the optimal embedding pattern. Thus, each solution to the problem is a binary vector corresponding to a variant of an embedding pattern.

The quality of the solution depends on the fitness function design. In our study, the fitness function combines imperceptibility and robustness metrics: peak signal-to-noise ratio (PSNR) and bit error rate (BER). A trial embedding of a watermark into an image is performed to calculate the fitness function value. Some current individual of the population is used as a pattern 0, and its inverted version is used as a pattern 1. PSNR metric value is calculated to evaluate differences between an original image and a corresponding watermarked image after trial embedding. PSNR metric is measured in dB, and a larger value of this metric corresponds to a better visual quality. We use the following formula to get the PSNR value:

$$\text{PSNR} = 10 \times \log_{10} \left( \frac{255^2}{\text{MSE}} \right), \quad (5)$$

$$\text{MSE} = \frac{1}{m \times n} \sum_{i=1}^{m \times n} (OI_i - WI_i)^2, \quad (6)$$

where  $OI_i$  is an original image pixel, and  $WI_i$  is a watermarked image pixel, and  $m \times n$  is an original (and watermarked) image size.

Next, a watermark is extracted from a watermarked image obtained after the trial embedding, and an extracted watermark is obtained. BER metric evaluates differences between an original watermark and an extracted watermark, and a lower BER value corresponds to a better level of robustness. The calculation of BER metric is performed by the formula:

$$\text{BER} = \frac{B_{er}}{B}, \quad (7)$$

where  $B_{er}$  is a number of extraction errors, and  $B$  is a total number of embedded bits.

The fitness function to be maximized during the optimization process is given by the following equation:

$$\text{fitness} = \frac{\text{PSNR}}{\alpha} + (1 - \text{BER}), \quad (8)$$

where  $\alpha$  is a coefficient that balances imperceptibility and robustness.

#### IV. EMBEDDING AND EXTRACTING ALGORITHMS

The watermark embedding algorithm is formulated as follows.

*Input:* an original image  $OI$ , an original watermark  $OW$ , a set of synchronization block numbers  $S$ , a quantization step  $q$ , GA parameters.

*Output:* a watermarked image  $WI$ .

*Step 1.* Generate patterns 0 and 1 using GA as described in subsection III.B.

*Step 2.* Divide the original image  $OI$  into  $N$  non-overlapping  $8 \times 8$  pixel blocks and apply DCT to each block.

*Step 3.* For each  $i$ -th block,  $1 \leq i \leq N$ , do:

*Step 3.1.* If  $i \in S$ , embed pattern 0 into a synchronization block according to formula (1) and go to Step 3.3, otherwise go to Step 3.2.

*Step 3.2.* Separate a bit from the watermark  $OW$ . If it is equal to 0, embed pattern 0 into current block according to formula (1), otherwise embed pattern 1.

*Step 3.3.* Perform an inverse DCT of current block and round the resulting pixel values.

*Step 4.* Generate a watermarked image  $WI$  and finish the algorithm.

The watermark extraction algorithm is formulated as follows.

*Input:* a watermarked image  $WI$ , a set of synchronization block numbers  $S$ , a quantization step  $q$ .

*Output:* an extracted watermark  $EW$ .

*Step 1.* Divide the watermarked image  $WI$  into  $N$  non-overlapping blocks with  $8 \times 8$  pixel size and apply DCT to each block.

*Step 2.* Extract pattern 0 from each block whose number belongs to  $S$ , according to formula (2).

*Step 3.* Get pattern 0 by the simple majority principle.

*Step 4.* Extract watermark bits from each block whose number does not belong to  $S$ , according to formulas (2), (3), and (4).

*Step 5.* Generate the extracted watermark  $EW$  and finish the algorithm.



Fig. 2. Watermarks used for the experiments.

TABLE I. EXPERIMENTAL RESULTS

Sinc. block num.	2048	1024	512	256	128	64	32	16
<b>OI &amp; WI</b>								
PSNR	40.26 dB	39.97 dB	39.85 dB	39.84 dB	39.87 dB	39.86 dB	39.90 dB	39.95 dB
SSIM	0.9988	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987
<b>OW &amp; EW</b>								
NO	0.0001	0.0001	0.0000	0.0000	0.0056	0.0000	0.0001	0.0001
BC +10	0.0003	0.0004	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002
BC -10	0.0013	0.0004	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003
CC +10	0.0005	0.0006	0.0006	0.0005	0.0004	0.0015	0.0377	0.0633
CC -10	0.0410	0.0408	0.0334	0.0178	0.0279	0.0231	0.0300	0.0787
SPN	0.2337	0.2368	0.2484	0.2594	0.2672	0.2893	0.3067	0.3479
SHR	0.0363	0.0390	0.0280	0.0165	0.0216	0.0237	0.0282	0.0712
HE	0.1422	0.1399	0.1725	0.1863	0.1733	0.2239	0.2542	0.2608
JPG	0.3894	0.3611	0.3887	0.2961	0.2613	0.3165	0.3360	0.4454
GF	0.0132	0.0169	0.0093	0.0078	0.0113	0.0107	0.0196	0.0366
WSA	0.0513	0.0518	0.0418	0.0462	0.0560	0.0482	0.0533	0.0459
Average	0.0827	0.0807	0.0839	0.0755	0.0750	0.0852	0.0969	0.1228

## V. EXPERIMENTAL RESULTS

For the experiments, we used 8 standard images from the USC-SIPI image database [19], such as "Airplane", "Baboon", etc. All images were grayscale and 512×512 in size. As watermarks, we used two binary images 63×63 in size, shown in Fig. 2.

The patterns had a size of 34 bits and were embedded into 34 DCT coefficients in the mid-frequency region using the QIM method. The quantization step  $q$  was 10. In different experiments, we used every 2<sup>nd</sup>, 4<sup>th</sup>, 16<sup>th</sup>, 32<sup>nd</sup>, 64<sup>th</sup>, 128<sup>th</sup>, and 256<sup>th</sup> block as synchronization blocks, i.e. in different experiments there were 2048, 1024, 512, 256, 128, 64, 32, and 16 synchronization blocks, respectively. The size of the original watermark decreased as the number of synchronization blocks increased to 128 because the payload capacity also decreased. We used the following GA parameters estimated experimentally: the population size was 68 individuals, the number of generations was 30, the crossover probability was 0.7, and the mutation probability was 0.3.

We used the following image processing operations to evaluate the embedding robustness:

- brightness change by +10 (BC +10);
- brightness change by -10 (BC -10);
- contrast change by +10 (CC +10);
- contrast change by -10 (CC -10);
- adding "salt-pepper" noise with a density of 0.01 (SPN);
- sharpening (SHR);
- histogram equalization (HE);
- JPEG compression with quality 90 (JPG);

- Gaussian filtering with a window size of 3×3 (GF);
- adding a 160×160 white square over the image (WSA).

Table I presents the averaged results of the experiments with the proposed algorithm. The table contains the values of imperceptibility and robustness metrics depending on a number of synchronization blocks. OI & WI rows show the PSNR (5) and SSIM [20] metric values for an original image and its watermarked copy. In all cases, the value of PSNR metric is greater than 39 dB, and the SSIM metric value is greater than 0.99, which indicates a high invisibility of embedding. OW & EW rows show the BER metric (7) values for extracted watermarks without attacks on watermarked images (NO) and after different attacks on watermarked images. It follows from the obtained results that the proposed algorithm provides a good level of robustness. The level of resistance to JPEG compression and "salt-pepper" noise is lower than to other attacks, however, with a certain choice of the synchronization block number, it is possible to detect a watermark in watermarked images after these two attacks.

A study of the influence of the synchronization block number on the embedding efficiency shows that reducing the number of synchronization blocks to 32 leads to an improvement in the embedding imperceptibility, but also to a noticeable decrease in robustness. The use of a large number of synchronization blocks (512–2048) provides high imperceptibility and robustness, but significantly reduces the payload capacity, since synchronization blocks occupy most of the watermarked image blocks. Therefore, it is recommended to use from 64 to 256 synchronization blocks in practice. The best result corresponds to the use of 128 synchronization blocks. In this case, a binary watermark of 62×62 pixels can be embedded into a 512×512 grayscale image.

TABLE II. COMPARISON WITH SIMILAR SCHEMES

Ref. no.	Optimization	OI & OW	Performance indicators
[6]	PSO	OI: 512×512 (color, grayscale) OW: 32×32 (binary)	PSNR: 44.64–45.87 dB SSIM: n/a BER (no attack): 0 BER (different attacks): 0.0–0.2460
[7]	GA	OI: 512×512 (grayscale) OW: 32×32 (binary)	PSNR: 36.89–55.06 dB SSIM: 0.9379–0.9999 BER (no attack): 0–0.0957 BER (different attacks): 0.0019–0.3208
[8]	TLBO	OI: 512×512 (color) OW: 32×32 (binary)	PSNR: 39.95–40.76 dB SSIM: n/a BER (no attack): n/a BER (different attacks): 0–0.1816
Proposed	GA	OI: 512×512 (grayscale) OW: 62×62 (binary)	PSNR: 38.97–40.81 dB SSIM: 0.9976–0.9991 BER (no attack): 0 BER (different attacks): 0–0.3437

We compared the obtained results with some other watermarking schemes in the DCT and DCT-DWT domain, based on the use of metaheuristic optimization. The comparison results for key performance indicators are presented in Table II. PSNR and BER values correspond to individual images and attacks. As follows from the table, the proposed algorithm demonstrates indices of embedding imperceptibility and robustness comparable to analogues at a higher embedding capacity. The new algorithm can embed 3.7 times more watermark bits than other similar schemes. At the same time, it provides high level of imperceptibility and robustness. As noted earlier, in contrast to schemes [6–8], which use optimization to select the embedding strength value, the proposed algorithm solves the original problem of finding the optimal embedding pattern.

## VI. CONCLUSION

In this study, a new image watermarking algorithm was proposed based on QIM embedding operation in DCT domain. We took several approaches to improve the efficiency of information embedding. First, embedding redundancy was increased by using separate patterns to encode the watermark bits in order to improve robustness to image processing operations. We applied synchronization blocks that store information about pattern 0 and are used in the extraction phase to avoid extraction ambiguity. Secondly, GA was applied to select optimal patterns to balance imperceptibility and robustness. In the future, it is planned to develop the ideas presented in this study, including to investigate the effectiveness of other metaheuristics for the problem being solved and to evaluate the effectiveness of the proposed method for other frequency transformations. We also plan to further explore the application of coding theory techniques to pattern generation to improve the efficiency of our watermarking scheme.

## REFERENCES

[1] M. Ghadi, L. Laouamer, L. Nana, and A. Pascu, "A blind spatial domain-based image watermarking using texture analysis and association rules mining," *Multimed Tools Appl*, vol. 78, no. 12, pp. 15705–15750, Jun. 2019.

[2] X. Zhang, Q. Su, Y. Sun, and S. Chen, "A robust and high-efficiency blind watermarking method for color images in the spatial domain," *Multimed Tools Appl*, vol. 82, no. 18, pp. 27217–27243, Jul. 2023.

[3] Y. Luo et al., "A multi-scale image watermarking based on integer wavelet transform and singular value decomposition," *Expert Systems with Applications*, vol. 168, p. 114272, Apr. 2021.

[4] Z. Yuan, D. Liu, X. Zhang, H. Wang, and Q. Su, "DCT-based color digital image blind watermarking method with variable steps," *Multimed Tools Appl*, vol. 79, no. 41, pp. 30557–30581, Nov. 2020.

[5] A. Melman and O. Evsutin, "Image data hiding schemes based on metaheuristic optimization: a review," *Artif Intell Rev*, Jun. 2023.

[6] S. Sisaudia and V. P. Vishwakarma, "Copyright protection using KELM-PSO based multi-spectral image watermarking in DCT domain with local texture information based selection," *Multimed Tools Appl*, vol. 80, no. 6, pp. 8667–8688, Mar. 2021.

[7] S. A. Barlaskar, S. V. Singh, Anish Monsley K., and R. H. Laskar, "Genetic algorithm based optimized watermarking technique using hybrid DCNN-SVR and statistical approach for watermark extraction," *Multimed Tools Appl*, vol. 81, no. 5, pp. 7461–7500, Feb. 2022.

[8] M. Moosazadeh and G. Ekbatanifard, "A new DCT-based robust image watermarking method using teaching-learning-Based optimization," *Journal of Information Security and Applications*, vol. 47, pp. 28–38, Aug. 2019.

[9] A. Chacko and S. Chacko, "Deep learning-based robust medical image watermarking exploiting DCT and Harris hawks optimization," *International Journal of Intelligent Systems*, vol. 37, no. 8, pp. 4810–4844, 2022.

[10] B. Kazemivash and M. E. Moghaddam, "A robust digital image watermarking technique using lifting wavelet transform and firefly algorithm," *Multimed Tools Appl*, vol. 76, no. 20, pp. 20499–20524, Oct. 2017.

[11] X.-W. Li, Y. Liu, S.-T. Kim, and Q.-H. Wang, "Designing a genetic watermarking approach for 3D scenes," *Optics and Lasers in Engineering*, vol. 93, pp. 83–91, Jun. 2017.

[12] A. Kricha, Z. Kricha, and A. Sakly, "A Reframed Watermark Extraction Approach Using the ABC Algorithm," *Chinese Journal of Electronics*, vol. 30, no. 4, pp. 736–742, 2021.

[13] M. Saadati, J. Vahidi, V. Seydi, and P. Sheikholharam Mashhadi, "Proposing a New Image Watermarking Method Using Shearlet Transform and Whale Optimization Algorithm," *International Journal of Engineering*, vol. 34, no. 4, pp. 843–853, Apr. 2021.

[14] B. Chen and G. W. Wornell, "Quantization index modulation: a class of provably good methods for digital watermarking and information embedding," *IEEE Transactions on Information Theory*, vol. 47, no. 4, pp. 1423–1443, May 2001.

[15] X. Kang, F. Zhao, G. Lin, and Y. Chen, "A novel hybrid of DCT and SVD in DWT domain for robust and invisible blind image watermarking with optimal embedding strength," *Multimed Tools Appl*, vol. 77, no. 11, pp. 13197–13224, Jun. 2018.

[16] O. Evsutin, A. Melman, and R. Meshcheryakov, "Algorithm of error-free information embedding into the DCT domain of digital images based on the QIM method using adaptive masking of distortions," *Signal Processing*, vol. 179, p. 107811, Feb. 2021.

[17] D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*, 1st ed. USA: Addison-Wesley Longman Publishing Co., Inc., 1989.

[18] O. P. Singh, A. K. Singh, G. Srivastava, and N. Kumar, "Image watermarking using soft computing techniques: A comprehensive survey," *Multimed Tools Appl*, vol. 80, no. 20, pp. 30367–30398, Aug. 2021.

[19] "SIPI Image Database." <https://sipi.usc.edu/database/> (accessed Aug. 31, 2023).

[20] D. R. I. M. Setiadi, "PSNR vs SSIM: imperceptibility quality assessment for image steganography," *Multimed Tools Appl*, vol. 80, no. 6, pp. 8423–8444, Mar. 2021, doi: 10.1007/s11042-020-10035-z.