

Galactic Swarm Optimization Based Adaptive Digital Image Watermarking for Optimal Positions Detection

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Abstract—Over recent decades, myriad technologies of imaging and their applications have been skyrocketed. With the emerging of such technologies, images acquisition, storage, and distribution led to easier and fast processing and transmission. But, on the other hand, several issues of malicious copying, unauthorized manipulation, and felonious distribution are growing every day. In order to cope with these issues, as a promising technology, digital image watermarking has appeared. In general, the optimization techniques are in demand for providing optimal embedding for watermarks. In this paper, an adaptive blind approach of digital image watermarking has been proposed in which the algorithm of galactic swarm optimization (GSO) is used for detecting the optimal positions to embed a watermark in the high and middle frequencies of the discrete wavelet transformation (DWT) of the cover image. To prove the high performance of the presented approach, various experiments and comparisons were conducted. The acquired results showed robustness against several kinds of attacks and preserved a high imperceptibility.

Keywords— *Galactic Swarm Optimization Algorithm (GSO), Adaptive Digital Image Watermarking, Discrete Wavelet Transform (DWT), Optimal Positions Detection.*

I. INTRODUCTION

Recently, the progressing of internet technology led to a huge transmission or storing of digital multimedia. In the meantime, multimedia is becoming more vulnerable to copying, manipulations, and distribution without source approval. In this attitude, the appearance of digital watermarking technology represents a boon to coping with these issues [1]. This technology plays a considerable role to ensure the security of digital multimedia by including secret information into host multimedia. The techniques of digital image watermarking are used for concealing the watermark into the cover image. The efficiency of these techniques is assessed by utilizing the metrics of robustness and imperceptibility [2]. Therefore, it is very significant to present a robust watermarking technique capable of withstanding against several kinds of attacks together with preserving imperceptibility (image quality). In order to provide these requirements, frequency domain based watermarking should be utilized instead of spatial domain based watermarking, since the frequency domain techniques such as singular value decomposition (SVD), discrete cosine transform (DCT), and

discrete wavelet transform (DWT) possess high robustness in facing attacks [3]. Additionally, the appropriate positions for embedding watermarks in such frequency domains should be exploited to obtain a balance between imperceptibility and robustness.

Two decades ago, several meta-heuristic optimization techniques have appeared which played a significant role in real-life applications. At the application of digital image watermarking, for providing an optimal compromise between robustness and imperceptibility, the optimization techniques can be utilized for optimally detecting either scaling parameters or embedding positions. In this paper, an adaptive approach of grayscale image watermarking has been proposed in which a galactic swarm optimization algorithm (GSO) is used for detecting the optimal positions to embed a watermark in the high and middle frequencies sub-bands of DWT of the cover image. The residue of this paper is drawn as following; The next section displays a concise review of frequency domain based watermarking approaches based on various optimization algorithms. Section three presents significant preliminaries for the proposed approach. Section four demonstrates the proposed adaptive digital image watermarking approach. Section five demonstrates the performance valuation of the proposed approach. Lastly, section six summarizes the main conclusions.

II. RELATED WORKS

There are lots of approaches of digital image watermarking that are available in the literature are dealing with the aspects of finding the optimal scaling parameters and embedding positions. G.A. Papakostas et al. [4], proposed an approach of digital image watermarking depending on a simple genetic algorithm (GA) for searching an appropriate set of parameters to ensure watermarked images with high quality, in addition to obtaining low rates of bit error at the watermarks extraction. The experiments showed that this proposed approach is more robust and imperceptible. J. Waleed et al. [5], proposed an approach of grayscale image watermarking based on the cuckoo search algorithm (CS) for detecting the optimal positions to include the watermark in the domain of DWT of the cover image. The obtained results showed that this proposed approach has the lowest impact on the watermarked image quality with a proper level of robustness. I. Ahmad Ansari et al. [6] presented a

watermarking approach in which firstly, the host image is transformed using DWT, then, the block-wise SVD is applied on the low-frequency wavelet sub-band for including the watermark's principal component. The process of the principal component inclusion yields an approach without false-positive error. This process is accomplished based on using a set of scaling parameters. The optimal scaling parameters are obtained using the artificial bee colony algorithm (ABC). This presented approach showed visible performance improvement. Nasrin M. Makbol et al. [7], presented an optimal approach of SVD then integer wavelet transformation (IWT) image watermarking in which the watermark singular vector is included in the singular values of the low-frequency sub-band of the IWT cover image. The algorithm of multiple objective ant colony optimization (MOACO) is utilized for selecting the optimal scaling parameters. This presented approach illustrates a good imperceptibility with high robustness against various kinds of attacks. Zhigao Zheng et al. [8], proposed DWT-SVD based image watermarking approach in which the guided dynamic particle swarm optimization algorithm (GDPSO) is exploited for providing an optimal watermark scaling parameter. The obtained results illustrated a considerable improvement in robustness and imperceptibility better than using the PSO algorithm. The main limitation in reviewed papers is the need for guaranteeing the requirements of watermarked image [14] [15].

In this paper, a challenging problem in watermarking approaches is solved for guaranteed the requirements of watermarked image quality and robustness. An efficient approach was proposed for achieving a high-level of imperceptibility with preserving high robustness by using a proper evaluation function to be implemented during a GSO algorithm

III. BACKGROUND

A. DWT

DWT is very common in applications of image processing. DWT decomposes a grayscale image into several sub-bands, Low-frequency sub-band (LL), Middle-frequencies sub-bands (HL and LH), and High-frequency sub-band (HH). It is practicable to repeat the transformation of DWT on the Low-frequency sub-band for obtaining coarser and coarser scales of high and Middle-frequencies sub-bands [9]. The image decomposition using DWT is drawn in Fig. 1.

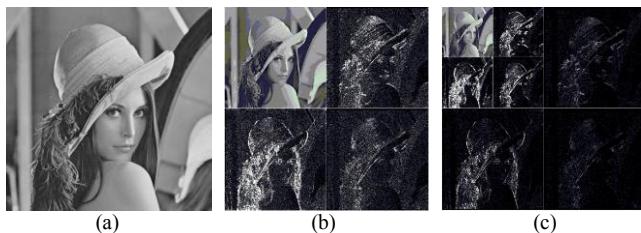


Fig. 1. (a) Lena grayscale image, (b) One-level DWT, (c) Two-levels DWT.

The main usefulness of DWT is possessing high accuracy of the human visual system comparing with the other transformed domains [10]. Therefore, the watermarks images can be included in the HH, HL, and LH sub-bands that are less sensitive to the human visual system. These sub-bands work on increasing the robustness of the watermark, with little influence on the quality of images [11].

B. GSO Algorithm

In 2016, V. Muthiah-Nakarajan and M. Mithra Noel [12], presented a new meta-heuristic optimization algorithm called galactic swarm optimization (GSO). The inspiration of GSO was obtained from the movement of galaxies, stars, and galaxies superclusters below the gravity influence. GSO utilizes multi-cycles of the stages of exploring and exploiting to reach an optimized compromise between exploring new solutions and exploiting present solutions. At the stage of exploring, independently, various sub-populations work on exploring the space of searching, and with the stage of exploiting, the preferable solutions of various sub-populations can be regarded as a super swarm and passed to the preferable solutions obtained via the super swarm. The algorithm of PSO can be utilized for updating sub-populations and the super swarm.

The algorithm of GSO imitates the locomotion of galaxies, stars, and galaxies superclusters in the cosmos. Stars are not uniformly distributed in the cosmos, however, they are clustered into galaxies that are not uniformly distributed. On a wide sufficient scale, individual galaxies seem as point masses. In the algorithm of GSO, the stars within a galaxy are attracted to large masses, and galaxies are attracted to other large masses. This process of attraction is imitated as follows: Firstly, individuals in every sub-population are influenced by preferable solutions in the sub-population regarding the algorithm of PSO. Then, every sub-population is indicated by the preferable solution obtained via the sub-population and handled as a super swarm. The super swarm includes the preferable solutions of each sub-population, whereby all individual's solutions will be influenced by global best [13].

Within the algorithm of GSO, the swarm represents "X" a set of D-tuples including elements ($X_j^{(i)} \in R^D$) which includes "M" sub swarms (All the galaxies of stars) " $X_i \subset X: i = 1, \dots, M$ ", with size "N" (Number of stars) for each sub swarm. The initialization of the stars in each "X" sub swarm are obtained randomly through the search space $[x_{\text{Minimum}}, x_{\text{Maximum}}]^D$.

In the 1st level of GSO, for each sub swarm, the algorithm of PSO is implemented separately, therefore, it should be run "M" of times. All sub swarms possess related global best $g^{(i)}$ and are updated when any of personal bests $p_j^{(i)}$ possess a function value smaller than $g^{(i)}, f(p_j^{(i)}) < f(g^{(i)})$. In each sub swarm, the stars are stochastically attracted to the preferable solution (local minimum) obtained by that specific sub swarm.

Each sub swarm X_i is moved independently without any impact on the sub swarm X_j , where $i \neq j$, this permits the possibility of a comprehensive and unaffected searching. For taking the total usefulness of this newfound capability of exploration for various sub swarms, the galactic best is denoted by "g" that is updated if any of the global bests $g^{(i)}$ includes a preferable function value, $f(g^{(i)}) < f(g)$. The algorithm of GSO conserves a record of the preferable solution via updating g. The whole sub swarms are searching separately in their space of searching, this searching initiates via computing the star's velocity $l_j^{(i)}$ and position. The updating of the star's velocity and position is as follows [12]:

$$l_j^{(i)} \leftarrow w_1 l^{(i)} + a_1 \text{rand}_1(P_j^{(i)} - X_j^{(i)}) + a_2 \text{rand}_2(g^{(i)} - X_j^{(i)}) \quad (1)$$

$$X_j^{(i)} \leftarrow X_j^{(i)} + l_j^{(i)} \quad (2)$$

Where, w_1 is the inertial weight, a_1 and a_2 indicate the acceleration coefficients, $rand_1$ and $rand_2$ are random numbers.

$$w_1 = 1 - \frac{q}{I_1} \quad (3)$$

$$rand_i = \cup (-1,1) \quad (4)$$

Where, q indicates the present integer number of iteration within 0 to I_1 , $rand_i$ is a selected random number (-1 and 1).

Global bests share in the subsequent clustering stage for forming the superclusters. The new super swarm S is generating via gathering the global bests from subs warms X_i .

$$s^{(i)} \in S: i = 1, \dots, M \quad (5)$$

$$s^{(i)} = g^{(i)}$$

The updating of velocity $l^{(i)}$ and position vectors $s^{(i)}$ is given in the following Equations:

$$l^{(i)} \leftarrow w_2 l^{(i)} + a_3 rand_3(p^{(i)} - s^{(i)}) + a_4 rand_4(g - s^{(i)}) \quad (6)$$

Where $p^{(i)}$ represents the personal best related to vector $s^{(i)}$, w_2 , a_3 and a_4 , $rand_3$ and $rand_4$ are the same parameters in equation (1). In this level, g represents a global best and when a better solution is obtained, g is updated, because the super swarm emphasis on the preferable of each sub swarm, at this manner the exploitation can be improved.

The galactic best position after the last epoch g and its evaluation value $f(g)$ are returning as minimum positions and cost, respectively via the algorithm.

IV. THE PROPOSED APPROACH OF GSO BASED WATERMARKING

In this section, an adaptive approach of grayscale image watermarking based on GSO is presented in which the cover grayscale image is decomposed using the DWT. Because performing any ease change to low-frequency sub-band will be perceptible to the human eye, consequently, the high and middle frequencies sub-bands represent appropriate positions that can be exploited in the watermark embedding process. Where only one bit of watermark image is included via changing one coefficient in each selected 8×8 block within the exploited sub-bands. The process of selecting the optimal blocks and optimal coefficients for including the watermark is accomplished using the algorithm of GSO. Fig. 2 explains the proposed embedding process, and the main steps of this process are as follows:

- 1) Utilize DWT with one level for decomposing the cover grayscale image C of size $n \times n$, and segregate the high and middle frequencies sub-bands.
- 2) Partition the segregated frequencies sub-bands to non-overlapped blocks (each of 8×8 pixels).
- 3) Reorder the binary image (watermark of size $m \times m$) into a vector of binaries $B = \{b_1, \dots, b_m\}$.
- 4) Count on the optimal blocks positions P detected by the algorithm of GSO. In order to include one bit from B into one block from P ;

- Firstly, pick out the odd positions from p_i " O_p ", then, pick out the largest coefficient " L_p ", and the smallest coefficient " S_p " from O_p . And, count on the optimal coefficient from O_p " F_p " detected by the algorithm of GSO.
- Secondly, If the B_i value is equal to one, then substitute F_p with $L_p + \varepsilon$, otherwise, substitute F_p with $S_p - \varepsilon$, where ε indicates a scaling parameter which is experimentally selected. This step is simplified in the following equations; for each block p_i :

$$O_p = Odd Positions(p_i) \quad (7)$$

$$F_p = \begin{cases} L_p + \varepsilon & If \ b_i = 1 \\ S_p - \varepsilon & If \ b_i = 0 \end{cases} \quad (8)$$

5) Proceed the inverse of DWT via involving watermarked and non-watermarked blocks to acquire the watermarked cover image C' .

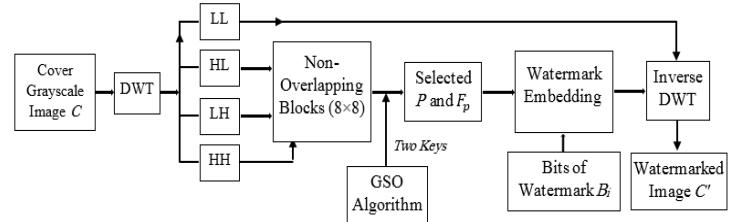


Fig. 2. The explanation of the embedding process.

The essential aim for using the algorithm of GSO is to detect the positions of optimal blocks, and detect the optimal coefficient in each detected block in the exploited DWT sub-bands to be utilized for embedding the watermark. The positions of detected blocks are utilized as a secret key. The main steps of GSO based image watermarking are briefly summarized as follows:

- 1) Initialize GSO parameters: The size of cover grayscale image is 512×512 , the number of galaxies (sub swarm) $M = 3072$, the number of stars (The number of O_p excluding L_p and S_p) $N=30$, and the number of iterations=500. Also, initialize the stars positions which are obtained randomly within 1 to 30, and the positions of sub swarms X_i which are obtained randomly within 1 to 1024, depending on the size of watermark image (32×32).
- 2) Perform the 1st level of GSO to obtain the optimal stars (F_p Coefficients) by using the metric of Peak Signal to Noise Ratio (PSNR) as the evaluation function.
- 3) Perform the 2nd level of GSO to obtain the optimal galaxies (Blocks) by using the metric of PSNR as the evaluation function.

$$PSNR = 10 \log_{10} \frac{255^2}{\frac{1}{n \times n} \sum_{i=1}^n \sum_{j=1}^n [C(i,j) - C'(i,j)]^2} \quad (9)$$

- 4) The galactic best positions after the last epoch and its evaluation value are returning as an optimal blocks positions.

In the blind process of watermark extraction, there is no need for the original cover image, and the steps of this process are as follows (see Fig. 3):

- 1) Utilize DWT with one level for decomposing the watermarked grayscale image C' , and segregate the watermarked high and middle frequencies sub-bands.
- 2) Partition the segregated frequencies sub-bands to non-overlapped blocks (each of 8×8 pixels).
- 3) Utilize the secret keys which represent the optimal blocks positions P' and optimal coefficient position in each optimal block detected by GSO and were used in the embedding process. In order to extract one bit b_i' from one block p_i' :

- Firstly, pick out the odd positions $O_{p'}$ from p_i' and $F_{p'}$ from $O_{p'}$.
- Compute the average AVG of the $O_{p'}$ coefficients, if $F_{p'}$ is larger than or equal to AVG then the bit of watermark is one, else, it is zero. This step is simplified in the following equations; for each block p_i' :

$$O_{p'} = \text{Odd Positions}(p_i') \quad (10)$$

$$b_i' = \begin{cases} 1 & \text{if } F_{p'} \geq AVG \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

Repeated this step until all watermark bits are extracted, and construct the extracted watermark image.

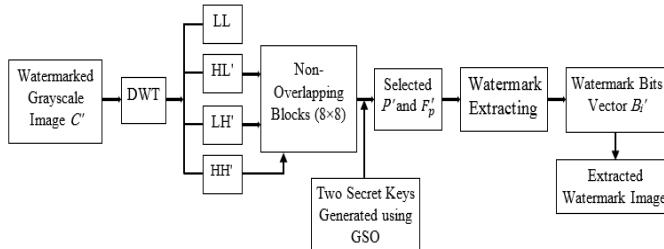


Fig. 3. The explanation of the extracting process.

V. THE EXPERIMENTS ANALYSIS

The proposed approach of GSO based adaptive watermarking is implemented using several grayscale images; Lena, Boat, Peppers, and Barbara, of size (512×512) . The binary image (watermark) of size (32×32) is utilized in the proposed embedding process. The utilized cover grayscale images and the watermark are shown in Fig. 4.

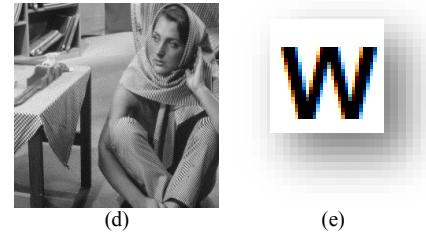
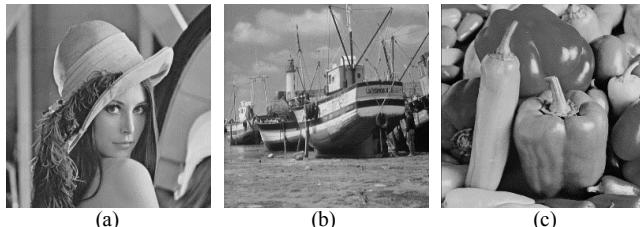


Fig. 4. The utilized Grayscale Images (a) Lena, (b) Boat, (c) Peppers, and (d) Barbara. (e) The utilized watermark.

The metric of normalized correlation coefficient ($Norm_C$) is utilized for measuring the extracted watermark robustness. The largest value of this metric is One (best robustness).

$$Norm_C = \frac{\sum_{i=1}^m B_i B_i'}{\sqrt{\sum_{i=1}^m B_i^2} \sqrt{\sum_{i=1}^m B_i'^2}} \quad (12)$$

The $Norm_C$ values of the extracted watermark without attack are equal to One, and the values of $Norm_C$ under various kinds of attacks with GSO algorithm and without using the GSO algorithm (random positions) are shown in Table I.

TABLE I. THE VALUES OF $Norm_C$ UNDER VARIOUS KINDS OF ATTACKS WITH AND WITHOUT USING GSO ALGORITHM.

Attacks	Without GSO				With GSO			
	Lena	Boat	Peppers	Barbara	Lena	Boat	Peppers	Barbara
Gaussian Noise	0.9354	0.9656	0.9599	0.8996	0.9443	0.9526	0.9557	0.8999
1% Salt and Pepper Noise	0.9437	0.9568	0.9594	0.9371	0.9425	0.9532	0.9549	0.9363
4% Salt and Pepper Noise	0.8228	0.8711	0.8398	0.8086	0.8152	0.8676	0.8533	0.8291
(3x3) Median Filter	0.8125	0.8085	0.8123	0.8571	0.8259	0.8106	0.8312	0.8598
Intensity Adjustment	0.9949	0.9989	0.9978	0.9975	0.9954	0.9987	0.9975	0.9968
Histogram Equalization	0.9983	0.9986	0.9977	0.9897	0.9988	0.9934	0.9987	0.9985
JPEG Compression	0.8202	0.8561	0.8398	0.8012	0.8214	0.8459	0.8459	0.8129
25% Cropping	0.9896	0.9924	0.9923	0.9892	0.9919	0.9957	0.9956	0.9895

Depending on the results in Table I, we found that the process of the optimization never affects the $Norm_C$ values and sometimes improves them, besides improving the imperceptibility.

The obtained results of PSNR values and $Norm_c$ values with and without using GSO algorithm are shown in Table II. Also, a comparison using the PSNR values and $Norm_c$ values of Lena image between the proposed GSO based watermarking approach and other related approaches is illustrated in Table III.

TABLE II. THE OBTAINED PSNR VALUES AND $Norm_c$ VALUES WITH AND WITHOUT USING GSO ALGORITHM.

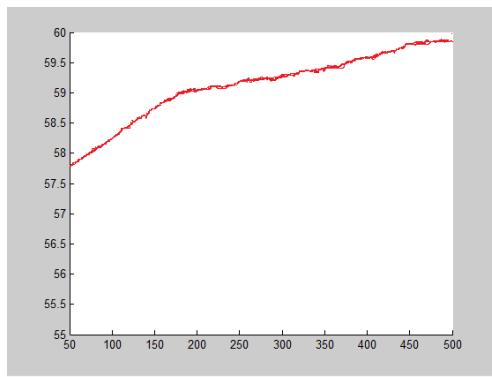
Images	PSNR With GSO	PSNR Without GSO	$Norm_c$ With and Without GSO
Lena	59.7919	57.8897	1

Boat	57.1092	53.0802	1
Peppers	59.1164	56.3587	1
Barbara	53.0185	49.9054	1

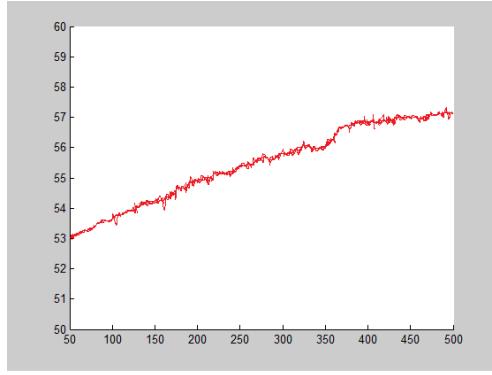
TABLE III. THE COMPARISON WITH OTHER RELATED APPROACHES.

Approaches	PSNR	Norm_c
G.A. Papakostas et al. [4]	43.9407	0.9916
J. Waleed et al. [5]	56.2356	1
Ahmad Ansari et al. [6]	33.0326	1
Nasrin M. Makbol et al. [7]	42.9245	0.9532
Zhigao Zheng et al. [8]	36.8777	1
GSO based approach	59.7919	1

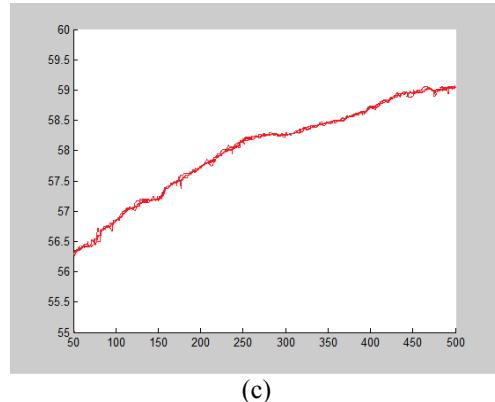
Figure 5 illustrates an obvious increase in the image quality (evaluation function) for reaching the optimal values using GSO algorithm.



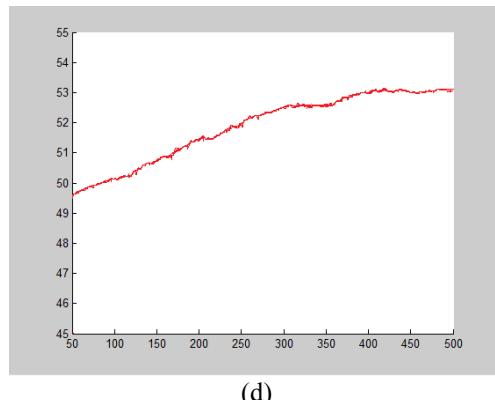
(a)



(b)



(c)



(d)

Fig. 5. The values of evaluation function versus the generations of GSO for (a) Lena image, (b) Boat image, (c) Peppers image, and (d) Barbara image.

VI. CONCLUSIONS

Obtaining the optimal level of minimal distortion with a guaranteed robustness requirement represents a challenging issue for digital image watermarking approaches. In this paper, an adaptive approach of digital image watermarking is proposed by combining a meta-heuristic algorithm with an efficient embedding process for achieving optimal performance. This proposed meta-heuristic algorithm based watermarking approach works on detecting the optimal blocks in the high and middle frequencies sub-bands of the DWT cover image. Also, detecting the optimal coefficient in each detected block in the exploited DWT sub-bands. These processes of detection are accomplished by using the GSO algorithm to be utilized for embedding the watermark bits with optimal image quality and providing high robustness. In future work, we will work on reaching minimal cover distortion with optimal robustness.

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