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Digital Image Watermarking:Framework,Optimization and AI for Enhanced Security

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Abstract - The advent of the technology and the advancement in the digitalization, there is a need for security of the data due to the compromise in the strong firewall. As a result, data encryption has evolved such as cryptography, steganography and digital watermarking. Recently, it has been observed that image sharing has become easier due to the portability of sharing the data. At the same time, it was observed that there is threat to the cyber security framework. Hence, in the current article, we review various aspects image watermarking frameworks and standards to design these frameworks will be presented. At the same time, new technologies such as machine learning and artificial intelligence have become a substantial interest, a framework which can envelope the current watermarking technique much more easily to design but with more sophisticated security.

Keywords: Digital Image Watermarking, Machine Learning, Optimization, Wavelet Transforms.

Introduction

Digital watermarking received significant attention in the scientific community due to the concern raised over cyber security. The term digital image watermarking refers to embed a secret message within an image. To an understanding, it can be inferred as steganography.Due to the advent of network technology, it was observed that content authentication, copyright protection and protection against duplication have foreseen a lot of attention. The image watermarking involves embedding watermark data into an image to protect from cyber threats, and allows the end user to decode the data using the similar watermarked product as sender.

An extensive review in understanding the digital watermarking techniques can be pursued from the review by [1]. It is not always desired that there are standard techniques, but they vary depending on the type of the applications. In this context, a work from [2] has emphasized various techniques based on which type of data is embedded. The article also emphasizes on the requirements, applications, detailed survey and guidelines for the development of watermarking algorithms. Due to huge computational and cloud storage capacities, data storage security is of high security concern, since the data is still and can be easily vulnerable to the threats such as data infringement, copyright distribution and unauthorized access. In such a scenario, a more stringent and complex security must be provided, an overview on various data image watermarking techniques when the data is still has been briefly emphasized in the work [3] followed by watermarking properties and evaluation system in [4].

Aforementioned earlier, most of the authors have discoursed that depending on the type of the application the algorithms and the type of the security is designed. The basic characteristics of the digital watermarking are capacity, false positive, imperceptibility and robustness of the watermarking algorithm. A detailed review on the framework with the above characteristics is highlighted in the work [5]. To understand a general framework for designing robust watermarking, an excellent paper is presented by authors [6] by introducing fair and unfair attacks which enables ease of classification of different systems and attacks. Most of the work they proposed is based on Diffie-Hellman's paradigm, which is the most widely used cryptography technique. They have identified the choice between the symmetric and asymmetric watermarking is still an interest of current research. An interesting article that emphasized on the asymmetric watermarking can be cited from [7], since most of the available watermarking schemes are symmetric implicating that key used for embedding watermark must be available at the end user i.e., the detector. This has a compromise when the data is shared across various users. Hence, asymmetric watermarking has received ample attention among the peers in the scientific community. But they received criticism on their robustness and a need to identify or enhance the robustness of asymmetric watermarking was presented by Furon and Duhamel and obtained a near robustness equivalent to that of symmetric watermarking [8]. Though the robustness is improved, there is still a compromise in the quality loss due to the attacks from the malicious software. These malicious attacks are difficult to identify due to the complicated architecture posed by the asymmetric watermarking. To realize the usability, robustness and performance between the symmetric and asymmetric watermarking, an excellent comparative study is suggested herein [9]. The authors in their work emphasized on the comparison of previous algorithms and have proposed a few new algorithms. We shall discuss this in detail in the algorithms section.

1. Literature Survey

Watermarking Framework

In order to have effective watermarking, the following characteristics must be desired such as Unobtrusive-watermark is perpetually made invisible, robust-must be difficult to remove, real-time performance-must not preclude on low-cost systems, modern capacity-most of the useful information must be embedded as an image and unambiguous-must be inherently identify the owner. The early watermarking techniques include least significant bit modification, correlation-based techniques, frequency domain techniques and wavelet watermarking techniques [10]. We shall discuss each of these methods in detail in the following section.

Least Significant Bit Watermarking

This method involves the conversion of image pixels to the binary form and the information is concealed in the bits of the pixel value. Change of the bit positions influence various parameters such as mean square error, peak signal to noise ratio and normalized cross correlation. A comparative study on these parameters for various noise attacks have been evaluated in the work [11]. However this technique can be easily modified due to its simple architecture and hence there is a need for development in this context. And a new method referred to as the least significant bit hash algorithm has been developed and a work in this context can be cited from the reference [12]. They have analyzed the performance of the algorithm using data capacity and histogram analysis and hamming distance. The applications of these algorithms have been cited in watermarking authentication [13] and medical image security [14].

Correlation Based Watermarking

Correlation based technique is a statistical technique that measures the authentication performance of the extracted signature and computed signature from the watermarked image. In context to an application using the correlation method, a work from [15] has demonstrated performance measurement using correlation. Initially the phase-magnitude domain of the fourier spectrum was used to embed the information into an image. Firstly, the phase signature of the image is hidden back into the magnitude of the Fourier transform at the embedding stage.

The detector will use the Fourier transform and extract the information. Hence the authentication performance based on the peak signal-noise ratio metric using the correlation is investigated. We shall refer to the following figure.1 that displays how an image is watermarked.

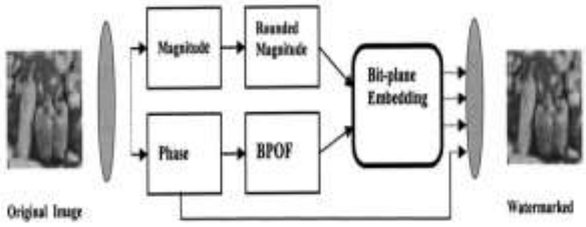

Figure 1. Binary Phase-only Filter Based Watermarking Framework

The figure.1 represents the phase and magnitude of the original image, where phase of the image is embedded under the magnitude of the Fourier plane through Binary Phase-Only Filter (BPOF) and the embed image can be seen as watermarked and respective image example can be inferred in the figure.2.

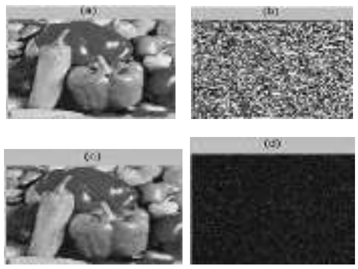

Figure 2. a. Actual Image b. The BPOF Signature c. Watermarked Imaged. Visually Enhanced Watermarked

The performance of this watermarking technique depends on the frequency characteristics of the watermark sequence. In order to improve performance, the embedding of high frequency spectrum of watermark in the low frequency of the DFT domain. An excellent work in this context can be cited from the literature [15] and it was found that superior performance and robustness to low pass attacks is achieved. It is always desired to have more robust watermarking and hence an ample amount of research has been well cited in the literature. Few to address are a normalized correlation-based quantization modulation [16], singular value decomposition (SVD) [17] and using digital signal processing (DSP) [18].

Frequency Domain Techniques

Frequency domain techniques have been widely used in the digital image watermarking due to their enhanced encryption and excellent performance and robustness. Frequency domain techniques are those in which the actual data is transformed in the transform domain wherein the transformed coefficients are perturbed by in small amounts vectorially to represent watermark. basically, the selection of these coefficients is very crucial which actually introduces the complexity in designing and also enhances the robustness and performance of the realized system. these coefficients can be of either a perceptual [19] or sometimes energy significance [20].

One of the critical challenges is identifying the copies of images on the browser has now become easy due to the introducing watermarking. The primary purpose of watermarking in the frequency domain is that the characteristics of the human visual system (HVS) are better captured by the spectral coefficients. For example, the HVS is more sensitive to low-frequency coefficients, and less sensitive to high frequency coefficients. For instance, consider a one-dimensional signal, initially the signal must be discretized into high frequency and low frequency groups, since it has first pass the low-pass and thereafter high-pass frequencies. The high-band frequency group would remain unchanged and the low-pass frequency would be further divided into two inner group frequencies enabling the second pass of the low-pass and pass frequencies. The same process is to be continued in such an arbitrary number of times making the next passes by dividing the low-pass frequency blocks [21]. Whereas in context to the still images that consist of two-dimensional signals, it must be decomposed into a Discrete Wavelet Transform (DWT) pyramid structure with various frequency bands as shown in figure.3.

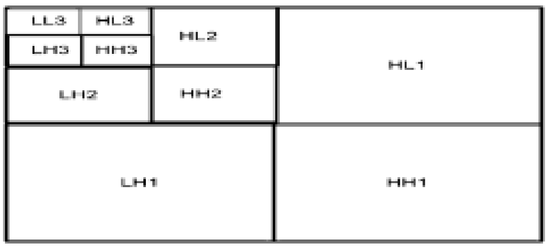

Figure 3. DWT Pyramid Decomposition of Image

Wavelet Watermarking Technique

Discrete Wavelet Transforms

DWT being one of the most powerful wavelet techniques of the frequency domain that requires less computational complexity and can decompose an image into various sub-bands with low and high-frequency wavelength functions. Discrete wavelet transform (DWT) is one of the powerful wavelet techniques of frequency domain which has a very low computational complexity. DWT also has an advantage of analyzing images of multi-resolution qualities and hence it allows the wavelet transform to be computed in different segments of time-domain images at various frequencies [22]. Multi-resolution analysis displays a good quality time resolution at high frequency and poor quality at low frequency. Whereas, high frequency resolution at high frequency and low frequency resolution at low frequencies [23]. Hence it is preferable to have short duration for high frequencies and vice versa.

Most widely used wavelet to decompose an image is the Haar wavelet, which is one among the other available wavelets such as the Daubechies wavelet. Haar wavelets are so simple to use and the oldest wavelet is still in use. DWT has a provision to choose a wavelet function of any kind due to its mathematical flexibility. Haar wavelets are scaled square shaped functions that form a wavelet. Works pertaining to use of Haar wavelets can be inferred from the literature, one such is to model non-linear wavelet transform based digital image watermarking that uses morphological Haar wavelet transform [24]. In their work, the authors demonstrated the performance of the morphological Haar wavelet transform algorithm is better than other ordinary discrete wavelet transforms. The method includes the original and watermarked images decomposed through a multiscale morphological wavelet transform. Further the watermark information is embedded into the original image at various resolutions. Wavelet transforms can be used to encounter geometric attacks providing a robust framework, in context to this an excellent work from [25] instigated use of Haar wavelet transform to embed the data into image. The embedding scheme involves reading the original logo images, applying DWT transform, then marking the selected coefficients followed by taking the inverse DWT transforms. Similarly, the extraction scheme involves reading the transformed original and watermarked images, then applying DWT transforms for both the images, mathematically subtracting the selected coefficients and finally checking the watermark for the authenticity.

Haar wavelets are also used to process the color image watermarking also and a relevant work in this context can be cited from [26]. The authors have addressed an interesting conflict between the effectiveness and robustness, wherein the effectiveness is good for high frequency when compared to low frequency but the robustness is compromised. Similarly, the vice versa is true, to ensure the fidelity between robustness and effectiveness, we have chosen a range of frequency of between low and high frequency to meet the both robustness and effectiveness. Few more works include [27-30]. The works include enhancement of the robustness, security and performance of the watermarking which uses Haar wavelet. Another work that uses single value decomposition which has better extraction even though the watermarked image is exposed to various attacks such as gaussian noise, blurr, cropping, gamma correction, contrast adjustment etc. An interesting work which enables the simple reverse embedding process without losing the data with ease is investigated using quantum image watermarking. At the same time, most of these image watermarking techniques are designated in the healthcare technologies where data privacy and security are of particular interest.

We have an overlook on using Haar wavelets, but there are other wavelets such as Daubechies wavelets which are most predominantly used in the late twentieth century by Daubechies developed in her ceremonial talk in 1988. These wavelets are a family of orthogonal wavelets of DWT which uses a scaling function to calculate the N/2 smoothed values of the N dataset. Works pertaining to the use of these wavelets can be inferred from [31], wherein authors proposed a novel digital image watermarking technique based on DWT+DFT+SVD. Daubechies wavelet is used to perform DWT, DCT for compression and SVD to embed watermark in the image. Few more works pertaining to the robustness of using the Daubechies wavelet can be cited from [32-33]. We shall now discuss the continuous wavelet transform based image watermarking technique in the following section.

Continuous Wavelet Transforms

Continuous wavelets are also one of the effective wavelets transform functions used in the image wavelet decomposition technique. Digital image watermarking requires wavelet decomposition as aforementioned earlier, here we shall discuss a few continuous wavelets functions that decompose the image during watermarking. From the literature, it is easy to crack the continuous wavelet transforms because of its uniform structure and hence, only the early stage of the development of image watermarking has seen a potential, but later the discrete wavelet transforms have foreseen tremendous potentiality. In lieu of this, however, a little emphasis on the continuous wavelet transform will be cited herein. Basically, any discrete signal to be designed requires the structure of continuous wavelet transform. For instance, a work from [34] has discoursed on the use of discrete transforms derived from the continuous wavelet transforms were discussed in his work to perform image watermarking. The authors realized that to calculate the wavelet transforms, the data must be discretized in the Nyquist state so that no data will be lost during the sampling. Once the sampling is finished, the discrete wavelet series could be used. The authors also discoursed on the spread spectrum (SS) and pseudo noise (PN) to embed the watermark with the data. They have identified that it has displayed excellent robustness and security.

One of the interesting properties of the CWT is that it maintains uniform sampling rate in the time domain, using this advantage, a work from [35] proposed redundant wavelet transform (RDWT) to outperform the classical CWT and to some extent DWT in terms of robustness and post processing of image. The main objective is to enable signal detection and enhancement similar to that of CWT. The wavelet coefficient magnitudes play a crucial role as they give the important features of the background of the image. As aforementioned earlier, CWT cannot be completely ignored but their characteristics such as spatial-frequency covariable character in spatial domain is crucial in oddity in signals and edges. This characteristic based investigation can be ascertained from the work [36]. An interesting work from [35] that proposed a 2D continuous wavelet domain. They have embedded the watermark in the middle of the wavelet transform modulus matrix of the host image. This approach endows the rotation and shift variation characteristics in a very efficient way thus making the method very robust.

There is a constraint posed by the CWT to perform transform on the curves, to ensure that a curvelet transform in combination with CWT has been extensively investigated. One such work can be cited from [37], The novelty of the work is to derive the host coefficients of the edge surface area parameters from the human visual system so that attacks that mislead human perception can be reduced. This method was found to be reliable against vulnerable attacks and also robust to many other attacks comparable to the other CWTs. However, recently few interesting works of using this context to the DWT have received much more significant attention in the scientific community.

2. Optimization Techniques in Watermarking

Optimization has become one of the intriguing phases in any process since it reduces the time, removes the unwanted variables or parameters in the envelope of the process or system. It allows us to identify only those process variables which actually has influence on the performance of the system. But this works with trial and error in product manufacturing, whereas when it comes to software, it may be influenced by a number of parameters and with a strong mathematical framework. Thus, to realize these complexities, evolution of optimization techniques for software development and process have been foreseen. However, when it comes to security, optimization is very difficult since there is no compromise of a variable that is a part of the framework of the security system. Due to the advent of technology, nature inspired processes have received significant attention in the scientific community. The nature inspired process is very complicated and cracking their envelope of parameters in a particular space is tedious. Hence such systems are most apt for the digital image watermarking techniques. In lieu of this, genetic algorithms, meta-heuristic algorithms have come into existence.

By nature, digital image watermarking is itself an optimization technique and hence use of genetic algorithms have shown potential inclination in this context. Early research was on using the discrete cosine transform with genetic algorithms, a few works may be cited from literature [38-39]. They have used the genetic forms of chromosomes and optimization parameters as reproduction, crossover and mutations were used [38]. It was concluded that an enhanced performance is obtained and also the embedded image is well correlated to the energy distribution of DCT blocks. In another impressive work, genetic algorithms were specifically used for performance optimizers [39]. Alongside few more interesting works, which transformed the name of digital watermarking into genetic watermarking based various techniques such as various wavelet transform domains. One to include is, a work from [40] which used a fitness function to to envelope both robustness and invisibility. The results also discoursed superior quality of image whilst using genetic algorithm. In general, the flow of genetic algorithm can be understood from the figure below.

Figure below explains defining the parameters which are generally the parameters used to embed the image. Fitness functions give the relation between the desired parameters and its value. Then the parameters are represented and individuals are created to evaluate the fitness value, further proceed with the crossover and then mutate. The mutation will be repeated until the fine convergence is obtained, and the above steps will be repeated for each of the sequences until the convergence is achieved. Test for convergence plays a crucial role, if it is not satisfied, we shall change the fitness value based on the convergence achieved and the numerical method will proceed to ensure the fitness value and the convergence is mapped and achieved.

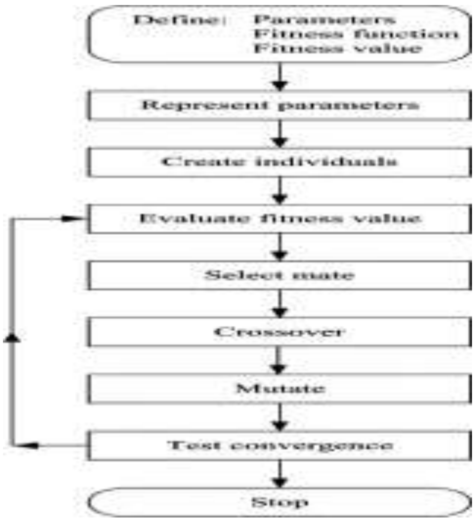

Figure 4. Parameters

Few more interesting works pertaining to the optimization technique for digital image watermarking mostly based on genetic algorithms can be cited in [41-45]. [41] proposed a robust method for digital image watermarking in discrete cosine transform domain using genetic algorithm and coefficient exchange approach, wherein the coefficient exchange for embedding watermark bits, whereas genetic algorithm for the Y component coefficients of image. This mapping enables the balance between the watermarking transparency and robustness. Alongside, grayscale digital image watermarking has also been optimized through genetic algorithms and has displayed better robustness and imperceptibility. The embedding of image was performed on the third level discrete cosine wavelet transform; this genetic algorithm mainly used to optimize the SVD coefficients of the embedded image. The authors in the work [42] test their robustness under various attacks. One more interesting work from [43] who introduced a genetic algorithm wherein the algorithm does not require the original image during the watermark extraction. These authors have developed the optimization to enhance the quality of the image watermarking. They have identified that this method can develop the quality of the watermarked image and give more robustness of the watermark when compared to other available works in the literature.

A similar work as discussed earlier [42] on the use of genetic algorithms on the gray image watermarking can be cited from [44], the only difference is GA optimizes the imperceptibility and robustness by identifying the best scaling factor. Most of the available digital image watermarking techniques lack fidelity and suffer from compromise and hence there is need to enhance the fidelity. As a result, an interesting work using a Roulette-wheel based genetic algorithm was proposed using the center of mass selection operator to trace the optimized location for insertion of digital watermark in the cover image [45]. The procedure involves representing the image in a new dimensional vector and evaluating its fitness, once the fitness of each chromosome is evaluated, then center of mass selection must be performed and finally crossover and mutation will be performed for various scales of probability to give best performance. Just like roulette wheel selection, there are other methods such as rank selection, steady state selection, tournament selection, elitism selection, reward-based selection, truncation selection and Boltzmann selection are few to name.

Rank based image watermarking basically displays the high embedding capacity followed by robustness to the malicious attacks; few works in this context can be cited from [46-47]. Wherein [46] proposed a method, where host image will be segmented to a 2D discrete cosine transform in each block, where to the each of the block, a coefficient sets will be constructed, to these sets actually the secret key is employed randomly and then embedded into watermark, and further it will be segment in combination by integrating the discrete cosine transform. Due to the characteristic of free of host signal interference, the usage of the error buffer in embedded watermarking produced significantly enhanced robustness against malicious attacks. In reference to steady state selection, a work from [48] proposed a digital image watermarking on the discrete wavelet transform with quantization. They have used blind watermarking scheme based on the discrete wavelet transform by quantization of the domain coefficients whilst applying the steady state selection method as the preferred genetic algorithm. The generic algorithm used the step size and strength as the important factor. The authors concluded that the proposed scheme is found to be robust against various threats.

There are works reported on the digital image watermarking with tournament selection based genetic algorithm-based approach and have shown better robustness but this operation wasn't much preferable due to the time complexity of the tournament selection and hence not much interest has been gained in the scientific community though it produces better robustness. Few works in this context can be reported from the literature [49-50]. Similarly, few works on the elitism selection operator based genetic algorithms were proposed to optimize the digital image watermarking. This elitism involves predicting the best solution may be one or from the group of solutions and will be mutated without undergoing any change, as a result the strategy speeds up the convergence of the algorithm. So in more precise terms, this elitism is performed in the combination of various other operators and also in the hybrid configuration of generic algorithms for better results. One such work can be cited from the literature which used particle swarm optimization as a combination to genetic algorithm and found to display excellent performance characteristics and robustness to various attacks [51]. Few more works on using elitism can be cited from the scientific literature [52-55]. There are ample works due to the feasibility and provision to speed up the convergence of the system process. Elitism has been used in combination for genetic algorithms such as to fool deep neural networks, multiobjective evolutionary algorithms and nature inspired algorithms. Often most researchers consider this to be more effective and have been significantly used as an operator for its versatility towards any system development.

To repeat the correlation generation i.e., for convergence, a new population of chromosomes has to be created and this is selected from using the truncation selection method which will be done by the previous population. The advantage of this method is that it ensures that no chromosomes are lost from the previous population and this process is called elitism [56]. They have proposed an excellent model and hence it has displayed excellent robustness to attacks.

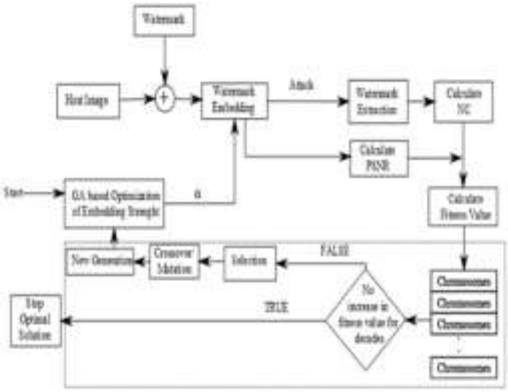

Figure 5. various fitness operators used in the genetic algorithms

We have seen various fitness operators used in the genetic algorithms and found their role in enhancing the robustness and clarity of the image. We shall now discourse on the evolutionary algorithms that are used to optimize the best digital image watermarking. Evolutionary algorithms are those inspired by the mechanism replicating biological evolution such as reproduction, recombination, mutation and selection. These are population-based metaheuristic methods. Few methods to include, swarm algorithms such as ant colony optimization, particle swarm optimization, cuckoo search, runner root algorithm, bee's algorithm, artificial bee colony algorithm are a few. Whereas other population-based metaheuristic methods can be hunting search, memetic algorithm, gaussian adaptation, adaptive dimensional search, firefly algorithm and harmony search are few to name. We shall now discourse each of them that have been pursued to perform the optimization of various parameters and factors that decide quality, reliability, robustness, strength, fidelity of the digital image watermarking in brief.

A lot of emphasis can be retrieved from the literature on these algorithms and ant colony optimization is one such technique which received wide attention in the scientific community. Few works pertaining to digital image watermarking using these algorithms can be cited from [57-59]. The ant colony optimization outlines in a way, initially we have to define the parameters such as colony size, initial trail phenomena, dissolving rate, then create an initial colony, this enables to evaluate the objective function to take its path length and measure of each ant, this complete process will finish tour (i.e., optimizes the nearest route between nest and food source) then updates the optimized route to the trail phenomena and the process will be repeated until the convergence is achieved. Once the convergence is achieved it will stop the criterion after the updating of the phenomena trial without further updating it to objective function. This process must be mapped to the watermarking algorithm satisfying the parameters and hence require careful examination. A brief of this can be cited from the literature [57]. The authors provided excellent emphasis on the algorithm framing in detail. Similar to this, [58] used ant colony optimization for image watermarking along with a light gradient boosting algorithm. The use of light gradient boost algorithms is used to predict optimized embedded parameters required for the new image that must be embedded. This boost algorithm consumes less time to identify the optimum parameters. The testing data is performed based on the optimization and computing the feature vector. Wherein the computing vector will train the observational data that is used in the testing phase and parallely the optimization will also train for optimum solution in the same observational data. The observational data is then subjected to a light gradient boosting algorithm which actually tries to predict the optimum solution. On the other hand, the new testing data when given as input directly envelopes to compute the feature vector and will be tested to be configured to a boosting algorithm which gives predicted optimum solution as aforementioned earlier. They have identified that this method is better than population based meta-heuristic approaches. Towards ant colony optimization, there were many works that can be cited from literature and we restrict in the current review on how to identify fitness value, optimize the embedded parameters, and framing of objective functions.

Particle swarm optimization is a set of particles in a particular space trying to find the optimal solution within the given space by updating all particles to the new optimal solution each time. This in fact has a problem that no optimal solution can be ever found due to its update of a new optimal solution with all other particles. However, there is also substantial work cited in the literature on the use of particle swarm optimization, one such interesting work could be from [60], the authors proposed the implementation of optimization technique onto a discrete wavelet transform. In their work they have studied the 3-level discrete wavelet transform. The process flows from initialization through decomposing to 3-level discrete wavelet transform and embed with pretreated watermark. When the embedded image is subjected to attacks, each of the attacks with individually extracted give a similar watermark, now adding the perceptibility index together will enable it to compile the fitness parameter. This is where actually the role of optimizer is important, since it decides whether a module has to go for termination with optimal parameters or reinitialize the decomposition.

An excellent work from [61] that uses particle swarm optimization to optimize the embedded parameters for a dual discrete cosine transform and multi-level discrete wavelet transform based, referred to as robust dual-embedded watermarking algorithm is proposed. The authors concluded that the algorithm can be extended for the copyright protection for color images, it can also be used for audio and video. It was also found that the proposed method has enhanced the security of the watermarking algorithm. In a similar context there are substantial works in the scientific community. New algorithms have come into existence, as a result, one such widely recognized during the last decade was cuckoo search algorithm and pertaining to digital image watermarking, this algorithm has been reported in wavelet domain to embed optimal image watermarking. Authors have used to find the optimal scaling factors to enhance the robustness and imperceptibility at one- or two-level discrete wavelet transforms. They have identified that these approaches have shown significant robustness to various attacks and it was also conferred that they can be applied to the images comprising ppir quality image and also on the distorted images too [62]. One more interesting work in this context can be cited on gray scale image watermarking, to the intuition noticed by the author, we feel implementation of any optimization or wavelet transforms and algorithms on gray scale image watermarking will serve as a base to realize the potential of particular technology. A discrete wavelet transform based gray scale image watermarking using cuckoo search algorithm has been investigated by the authors in their work [63]. An interesting approach is presented by the authors, by splitting the gray image into four sub-bands using wavelet transform, out of which two sub-bands have been selected where the mathematical equation of area can best fit the cuckoo search algorithm. This enabled the supremacy and lowest effect of PSNR values and interestingly optimum positions have been obtained for the watermark included images also. Few other works on cuckoo search algorithms can be referred from the works [64-66].

Nature inspired received tremendous inclination due to their interesting characteristics that makes optimization more feasible and hence one such interesting work can be found in [67], where authors proposed Bee algorithm. Bee algorithm is inspired from the nature of the honey bees where they optimize to search the best quality flower patches over a range of distances. They proposed the algorithm that mimics the behavior of the bees to embed the watermark in the discrete wavelet transform, thus resulting in the best quality of image with high imperceptibility and robustness. The process implementation of the bee algorithms begins with the initialization of the population of bees, then the fitness of the population is evaluated. To this evaluated fitness, we shall perform the exploitation where the select, recruit and fittest bee from each patch is selected and the rest of the bees will start exploring randomly the best patches. These bees are now a new population of scout bees that evaluate the fitness of the population and further to exploitation phase and circle continues so on. One more interesting work on the optimization of single value decomposition through artificial bee colonies for digital image watermarking has been reported in the literature [68]. The interesting aspect of the work is that the embedding blocks are selected on the basis of the human visual system and are embedded into a left singular vector matrix of decomposed and right singular vectors with compensation parameters. Now the bee colony optimization is employed to optimize the right and left singular vectors that consist of watermark bits and compensation parameters. This reported better visual quality and almost a decent robustness to the malicious attacks. Few other works pertaining to the bee colony optimization implementation on digital image watermarking can be pursued from [69-71].

We shall now discourse the population based heuristic approaches for optimization of the embedding parameters towards digital image watermarking. The most widely used population-based metaheuristic algorithm is the hunting algorithm. Hunting algorithms are inspired by the characteristic nature of the wild species. Based on this perspective various algorithms such as whale optimization algorithm based digital image watermarking approach can be cited from [72] that reported deriving the multiscale factors (MSF) to tailor the tradeoff between the invisibility and robustness. At the same time, the modified whale optimization algorithm ensures less number of parameters required to optimize the number of parameters required for the embedded image. Another advantage of the algorithm is that its implementation doesn't require gradient information. The process of algorithm involves initialization of n whales and whale population follows with respect to the objective function framed and optimizing the embedded parameters to meet the fitness function. Once the objective function and fitness is obtained the whales start optimizing until desired robustness is obtained through rigorous iterations. Few other works on whale optimization can be noted from [73-74]. One more interesting hunting-based algorithm is shark smell optimization. The authors in their work [75] have displayed a potential use of novel features such as human visual system, fuzzy inference system, back propagation neural network and shark smell optimization. Since the use of the human visual system as a parameter, it is easy to make an image invisible. And the idea of using the shark optimization algorithm is to identify only one ideal embedding parameter. It was concluded from their work that shark optimization has proven to give the best optimized embedded parameter rather than the particle swarm optimization and ant colony optimization. Few other works on shark optimization include the works [76]. Though there are decent works available in the literature which are less cited due to their intriguing complexity and lack in achieving the desired robustness and quality of the embedded image. However few works include memetic algorithm which is an extension of existing genetic algorithm [77] at the same time it induces likelihood of premature convergence, firefly algorithm [78] which actually identifies ideal embedding parameters to balance robustness and transparency which are crucial for any digital image watermarking to be reliable, grasshopper optimization algorithm [79] and bat algorithm [80] are few to name. These optimization techniques allowed researchers to identify the best embedding parameter so as reducing time and improving the robustness. We shall now look into the machine framework for the aforementioned digital image waterking based steganography.

3. Machine Learning Framework

The advancements in technology have led to significant progress in computational power and big data, enabling the emergence of machine learning. Machine learning and artificial intelligence have become disruptive techniques with diverse applications in fields such as biomedicine, healthcare, aerospace, the Internet of Things, and various industries. Consequently, machine learning techniques are being employed to address the need for improved security and encryption. This has generated a substantial body of literature in the scientific community. A noteworthy study [81] explores the role of machine learning in digital watermarking, specifically focusing on overcoming challenges related to attacks on watermarked images. The authors utilize a fully convolutional neural network to effectively reduce noise during encryption and decryption processes, employing the Spread Transform Dither Modulation (STDM) and Spread Spectrum (SS) watermarking schemes. Their research demonstrates that the selected machine learning algorithm outperforms other techniques when subjected to various attacks. Another intriguing study [82] delves into the utilization of deep learning for generating random digital image watermarks and embedding them in data without disturbing the original database.

An intriguing addition to the research includes the introduction of a blind color image watermarking scheme utilizing the YCbCr color space and Integer Wavelet Transform. This scheme incorporates a machine learning-based neural network architecture for copyright protection. By employing an artificial neural network (ANN), the complexity is reduced, and the discretization of the Y channel into blocks requires secret keys, ensuring security. Extensive testing against various attacks has demonstrated excellent performance in terms of imperceptibility and robustness. The results provide compelling experimental evidence, highlighting the method's high efficiency and minimal computational time requirements [83].

Furthermore, a comprehensive review [84] emphasizes the utilization of machine learning, artificial intelligence, and machine learning for digital image watermarking. Another noteworthy study [85] proposes an automated image watermarking scheme based on deep neural networks. Notably, the training algorithm operates in an unsupervised manner, eliminating the need for human intervention and annotation. The scheme also demonstrates excellent robustness when applied to images captured by phone cameras.

The integration of machine learning with the Discrete Wavelet Transform (DWT) domain enhances reliability and robustness for image watermarking applications. This connection is explored in a study [86] that introduces machine learning modules such as Extreme Learning Machine (ELM), Online Sequential Extreme Learning Machine (OSELM), and Weighted Extreme Learning Machine (WELM). The algorithms exhibit exceptional performance and efficacy when subjected to various attacks, including blurring, cropping, JPEG compression, noise addition, rotation, scaling-cropping, and sharpening. Reinforcement learning-based approaches are particularly preferred, as they provide support for both supervised and unsupervised algorithms, catering to specific problems in the field.

Given that machine learning is currently a disruptive technique, its impact on various domains, including image watermarking, has witnessed a significant rise. Deep learning and neural networks stand out as the most commonly employed machine learning modules in this context. Therefore, a substantial body of literature focuses on deep learning and neural network-based digital watermarking. One noteworthy study [87] introduces a reinforcement learning-based framework for developing blind watermarking techniques known for their high robustness. By utilizing convolutional neural networks (CNNs) for watermarking, the proposed network scheme demonstrates superior robustness when compared to classical watermarking techniques. Despite extensive research, it is crucial to assess the practicality of these techniques in real-world applications. In this regard, a study [88] presents a cooperative neural network framework using a discrete cosine transform (DCT) network for neural network-based digital image watermarking, specifically in the context of smart city applications. This approach offers the advantage of obtaining an optimal peak signal-to-noise ratio (PSNR) and marks the first usage of the cooperative neural network framework. However, it is important to recognize that deep learning approaches are not always inherently robust and may have limitations. To address these drawbacks, an interesting paper highlights the essential requirements for artificial neural network (ANN) models in the field of watermarking.

In recent years, Convolutional Neural Networks (CNNs) have emerged as the most popular network architecture for deep learning in image processing, showcasing excellent performance. During the construction phase of WMNet, which aims to facilitate medical image registration, the user's intended watermark is subjected to simulated attacks to generate a large number of distorted watermarks. A detection threshold is then established, and these watermarks are categorized as either "Correct" or "Incorrect." Subsequently, a convolutional neural network is employed to create WM Net, enabling the subsequent detection of watermark ownership. This approach offers a more objective method for identifying the image owner. An exemplary study in this domain is presented in [89].

4. Conclusion

In conclusion, digital image watermarking has emerged as a crucial technique for protecting the ownership and integrity of digital images. Over the years, significant advancements have been made in the field, particularly with the integration of machine learning and deep learning approaches. Machine learning algorithms, such as convolutional neural networks (CNNs), have demonstrated exceptional performance in various aspects of digital image watermarking, including robustness against attacks and imperceptibility. Researchers have explored different methodologies, including blind watermarking schemes, cooperative neural networks, and reinforcement learning-based frameworks, to enhance the effectiveness and reliability of digital image watermarking techniques. These approaches have showcased promising results in terms of high robustness, optimal peak signal-to-noise ratio (PSNR), and objective methods for watermark ownership detection.

However, it is important to consider the limitations and challenges associated with digital image watermarking. Deep learning approaches, while powerful, may also present certain drawbacks and require careful consideration of factors such as training data, network architecture, and generalizability. Additionally, the feasibility and practicality of these techniques in real-world applications, particularly in domains like medical image registration and smart city applications, need to be further explored and validated. Despite these challenges, digital image watermarking remains a vital tool for ensuring copyright protection, authenticity verification, and data integrity in various industries, including biomedicine, aerospace, and the Internet of Things. Continued research and innovation in the field of digital image watermarking, combined with advancements in machine learning and deep learning, will pave the way for more robust, efficient, and secure watermarking techniques in the future.

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