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MULTI-OBJECTIVE GENETIC ALGORITHM OPTIMIZATION FOR IMPROVED ROBUSTNESS AND TRANSPARENCY IN IMAGE WATERMARKING

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ABSTRACT

Finding the optimal trade-off between watermark longevity and perceptual transparency is the goal of multi-objective evolutionary algorithm optimization for image watermarking. To achieve this goal, we optimize the Singular Value Decomposition (SVD) and the Lifting Wavelet Transform (LWT) using Multi-Objective Genetic Algorithms (MOGAs). Combining AI with signal processing provides a fresh perspective on the challenges of picture watermarking. Finding the MSFs' sweet spot of performance could be challenging. These numbers, however, are the outcome of a genetic algorithm optimization with many objectives. The experimental evidence demonstrates that the suggested technique outperforms the present standard in terms of reliability and clarity.

Keywords: Genetic Algorithm, Robustness, Transparency, Image, Watermark

I. INTRODUCTION

In the vast realm of digital information and multimedia content, ensuring the security and integrity of digital assets has become a paramount concern. As our world continues its digital transformation, protecting the authenticity and ownership of digital media has emerged as a critical challenge. One prominent solution in this quest for safeguarding digital content is image watermarking, a technique that embeds hidden information, or "watermarks," into digital images to authenticate their source or ownership. However, the design of effective watermarking schemes is a complex and multifaceted task, as it necessitates a delicate balance between embedding imperceptibility and robustness against various attacks. Among the most promising approaches to this problem is the combination of Multi-Objective Genetic Algorithms (MOGAs) with cutting-edge image processing methods like Singular Value Decomposition (SVD) and Lifting Wavelet Transform (LWT).

The advent of MOGAs in the field of image watermarking represents a paradigm shift in the quest for achieving optimal solutions. Traditional watermarking approaches often struggled with finding a compromise between the conflicting objectives of watermark robustness and perceptual transparency. Robustness refers to the ability of a watermark to withstand various image processing operations and malicious attacks without being destroyed or significantly degraded, while perceptual transparency ensures that the presence of the watermark is imperceptible to human observers. MOGAs provide an elegant solution to this trade-off by enabling the exploration of multiple conflicting objectives simultaneously, allowing watermarking algorithms to find a set of solutions that represent a well-balanced compromise between these competing goals.

Two essential methods, singular value decomposition (SVD) and lifting wavelet transform (LWT), have significantly expanded the potential of picture watermarking. SVD is a matrix factorization method that decomposes an image into its singular values and matrices, providing a robust foundation for watermark embedding and extraction. LWT, on the other hand, is a powerful tool in the domain of signal processing, offering a multi-resolution framework that is well-suited for watermarking applications. When these techniques are integrated into the MOGA framework, they create a synergy that leverages the strengths of both optimization and signal processing to address the complexities of image watermarking.

As we embark on this journey, we will not only unravel the technical intricacies of Multi-Objective Genetic Algorithm Optimization for Image Watermarking but also witness the profound impact it has had on the broader landscape of digital content protection. This is a realm where science meets art, where mathematics and computation collaborate to preserve the integrity and authenticity of our digital heritage. Join us in this exploration of a cutting-edge technology that empowers creators, safeguards intellectual property, and secures the digital legacy of our rapidly evolving world.

II. IMPORTANCE OF IMAGE WATERMARKING IN DIGITAL CONTENT PROTECTION

Image watermarking plays a crucial role in digital content protection for various reasons. It provides a means to embed information, typically in the form of a digital signature or a mark, into multimedia content such as images, audio, and video. This embedded information serves several important purposes in the context of digital content protection:

1. **Copyright Protection**: One of the primary functions of image watermarking is to protect the intellectual property rights of content creators and owners. By embedding a watermark into their digital content, creators can claim ownership and establish a clear connection between the content and its rightful owner.

2. **Deterrence**: Visible watermarks or subtle, imperceptible watermarks can deter potential unauthorized use or distribution of copyrighted content. The presence of a watermark signals to users that the content is protected and should not be used without permission.

3. **Traceability**: Watermarks can include information about the copyright owner or distributor. This information can be useful in tracing the source of unauthorized copies or leaks, making it easier to identify and take legal action against copyright infringers.

4. **Content Authentication**: Digital watermarks can be used to authenticate the integrity

and authenticity of digital content. Users can verify that the content they are accessing or purchasing is genuine and has not been tampered with.

5. **Tamper Detection**: Watermarks can be designed to be robust against common image manipulations and alterations. If someone attempts to alter or remove the watermark, the tampering can be detected, indicating potential unauthorized modifications to the content.
6. **Data Provenance**: Watermarks can carry information about the history and usage of digital content. This is valuable in tracking the journey of content through various channels and platforms, ensuring its proper usage and adherence to licensing agreements.
7. **Forensic Evidence**: In cases of digital copyright infringement or other legal disputes, watermarks can serve as crucial forensic evidence. They can help establish a timeline of events and provide concrete proof of ownership.
8. **Content Tracking and Monitoring**: Organizations can use watermarks to track the distribution and usage of their content across the internet. This allows them to monitor where and how their content is being utilized and take action as needed.
9. **Brand Protection**: Watermarks are often used to protect brand identities and logos in images and videos. This ensures that brand assets are not misused or misrepresented by unauthorized parties.
10. **Enhanced Transparency**: In some cases, watermarks can enhance transparency by providing additional information about the content, such as its source, licensing terms, or metadata. This transparency can be beneficial in various applications, including journalism and art.

Overall, image watermarking is a critical tool in safeguarding digital content, preserving the rights of content creators and owners, and maintaining the integrity and authenticity of multimedia assets in the digital age. It enables content creators and rights holders to have better control over their intellectual property and helps deter unauthorized use and distribution.

III. REVIEW OF LITERATURE

Luo, Yuling et al., (2020) Image watermarking is widely used in many different information security contexts as an efficient method of copyright protection. There are four criteria it must fulfill: stealthiness, durability, capacity, and safety. In particular, the upper left corner is a reflection of the watermark's size. After that, by multiplying various scale factors, the watermark may be immediately implanted into four upper left portions. To fix the issue of false positives in SVD-based watermarking methods, a new optimized authentication methodology has been developed. In addition, a unique objective evaluation function is presented to find the ideal scaling factors in three dimensions, which may greatly enhance the algorithm's invisibility and resilience. The proposed watermark system is undetectable, as shown by experimental testing and comparative analysis, and resilient, as indicated by average normalized correlation values of 0.92.

Naik, M. (2018) Redundant Wavelet Transform, Singular Value Decomposition, and a Genetic Algorithm are the cornerstones of the paper's proposed Secure, resilient, and intelligent watermarking technique. Here is the solidity. To extract features, the proposed watermarking system uses RWT and SVD, while GA is used to optimize the scheme. In addition, this method suggests a signature embedding procedure to further strengthen the security of the watermarked picture. This method proposes using a Genetic Algorithm with intelligent properties and a more secure signing procedure. The suggested method is further strengthened by the integration of RWT and SVD. The suggested method is put through its paces in a slew of trials, with results analyzed using standard metrics like PSNR and NC to see how well it performs. The obtained experimental results prove that the proposed method outperforms the status quo by a wide margin, offering effective protection against attacks.

Wang, Chengyou et al., (2017) With the rapid development of computer technology has come several image altering techniques that significantly impact the security of image data. In order to guarantee the authenticity and integrity of digital images, digital watermarking technology has become an area of research. Improvements in singular value decomposition (SVD)-based picture watermarking techniques during the past few years are analyzed and evaluated. The mathematical theory of SVD is presented first, followed by a survey of watermarking methods. SVD watermarking's model, properties, and evaluation indices are also detailed here. Different SVD-based watermarking approaches, as well as hybrid watermarking strategies based on SVD and other transformations, are addressed for the purposes of copyright protection, tamper detection, localisation, and recovery.

Huang, Huang-Nan et al., (2015) In order to make SVD-based image watermarking more secure, this study employs optimization-based quantization on multiple singular values in the wavelet domain. After dividing the DWT's mid-frequency regions into a grid of square blocks, we apply a variety of singular value quantizations to include a watermark bit. An improved quality formula is provided to reduce the disparity between the unaltered singular values and the watermarked versions. To begin, a matrix definition of the performance index peak signal-to-noise ratio (PSNR) is presented. Then, a quality functional is created that optimizes the relationship between the performance index and the quantization method. After obtaining the formula for optimal quality using the Lagrange Principle, it is put to use in watermarking. The experimental findings demonstrate that increasing the number of coefficients used to embed a watermark bit does not degrade the watermarked image's PSNR or result in a worsening of the BER.

Mohammadi Ziabari, Seyed Sahand (2014) In this paper, we demonstrate the use of a genetic algorithm to improve an existing picture watermarking system such that it is more resistant to a certain kind of assault. There is a compromise to be made between stealth and security when watermarking images. The genetic algorithm is employed in digital picture watermarking to maintain both of these features while maintaining a meaningful value. The Centre of Interest Proximity Factor (CIPF), Complexity Factor (CF), and Priority Coefficient (PC) were all established to make picture watermarking more resistant to cropping assaults.

Loukhaoukha, Khaled et al., (2013) The primary goal of constructing a secure digital watermarking technique is to provide the most resilience feasible without sacrificing the visual imperceptibility. Using multi-objective particle swarm optimization (MOPSO) and singular value decomposition (SVD) in the wavelet domain, we suggest a method for producing watermarked images in this study. Singular value decomposition is applied to one of the ten sub-bands of recoverable information. The singular values from the selected sub-band are multiplied by multiple scaling factors (MSF) before being included into the watermark picture. The infinite permutations of several scale variables make it difficult to find ideal solutions. Therefore, multi-objective optimization of the various scaling variables is required to attain the maximum potential degrees of resistance and invisibility. To get the optimal values for the various parameters, particle swarm optimization is used here. Experiments conducted with the suggested technique demonstrate a considerable increase in stealth and resistance to common assaults.

Mubeen, M. et al., (2013) With the use of the Contourlet and Discrete Cosine transformations, this work introduces a new digital watermarking technique that successfully balances the competing needs of invisibility and durability. The best watermarking intensity (a) is determined using a multi-objective genetic algorithm. By considering the Human Visual System, the Contourlet transform improves quality while also making it more resistant to linear and non-linear filtering assaults. Discrete Cosine Transform with Zigzag scanning is used to identify the watermark blindly. Edge and surrounding sub-band coefficients are used in the watermark embedding process because they are less susceptible to distortion. Because it is picture adaptive, the suggested approach strikes a great balance between resilience and invisibility. The experimental findings demonstrate that the proposed approach is more secure against a wide range of attacks, including lossy JPEG compression with a quality of 5%, the Median filter with a mask of 6 6, resizing up to 20%, and a number of non-linear filtering assaults. The purpose of this work is to show how to modify a watermark sequence such that it only affects the frequency components of an image that are necessary for a secure and undetectable watermark to be generated.

Kejgir, Sushma & Kokare, Manesh (2012) Copyright protection and verification procedures for digital images using the lifting wavelet transform and singular value decomposition are offered.. In this study, the lifting wavelet transform (LWT) is used to segment the image into narrower frequency ranges. To successfully embed a watermark, a subband with energy greater than the estimated "Q" value must be located. The SVD matrix created for this subband is used to insert the digital signature at the gray level as a watermark. Due to the split-and-merge procedure of LWT, the computational cost of this watermarking is cut in half, making it suitable for real-time applications. Since down and up samples are not used in LWT based technique, there is less information loss compared to the discrete wavelet transform (DWT) algorithm. Additionally, the watermarking is rendered noninvertible by the use of SVD, preventing the creation of phony watermarked images. This spread-spectrum, semi-blind technique requires unique values from the original picture in order to get the watermark. There are five distinct photos used to evaluate the resilience of the proposed approach against a total of eighteen assaults. The research and experimental findings reveal that the suggested method may be trusted to determine ownership and is resilient against various threats. The suggested LWT-SVD technique is compared to the established DWT-SVD procedure for calculating correlation coefficients (CRCs).

Ramanjaneyulu, Kongara & Rajarajeswari, K. (2012) In this paper, we develop a robust and stealthy picture watermarking system that makes use of the discrete wavelet transform (DWT) to safeguard intellectual property. In order to remove a watermark, you don't need the unmodified source picture. Third-level DWT is applied to the original cover picture. Third- and second-level horizontal detail sub-band (LH2 and LH3) coefficients are arranged into distinct blocks. Each block should have one coefficient from the LH3 sub-band and four coefficients from the LH2 sub-band, as determined by the grouping of the coefficients. The watermark bit is used to find the first and second minimum in each block and adjust them accordingly. In order to produce the watermarked picture, an inverse DWT is performed to the changed coefficients of the sub-bands after watermark insertion. This paper develops a threshold-based decoder for watermark extraction. The genetic algorithm is used to optimize the parameters that characterize the embedding and extraction processes. The goal of optimization is to maximize the normalized cross correlation of the extracted watermark and the peak signal-to-noise ratio of the watermarked picture. When compared to other methods already in use, the suggested one shows substantial improvement in performance. The experimental findings show that this approach is resistant to a wide variety of visual assaults designed to decipher the watermark.

Loukhaoukha, Khaled et al., (2011) In this study, we provide an innovative watermarking technique that uses the lifting wavelet transform (LWT) and the singular value decomposition (SVD) to achieve maximum overall average correlation efficiency (MOACO). The detail sub-band of the host picture is where the unique binary watermark values are hidden. Multiple scaling factors (MSF) are used rather than a single one (SSF) so that watermarks may be as robust as possible without becoming unreadable. It might be difficult to determine the optimal MSF (multiple scaling factor). However, these results originated from a multi-goal ant colony optimization procedure. The experimental results demonstrate the superiority of the suggested approach over other watermarking techniques in terms of both transparency and robustness. Another perk of the suggested method is that it doesn't suffer from the problem of false positive watermark detections.

IV. RESEARCH METHODOLOGY

This study employs three 256x256 grayscale photos and a 32x32 binary watermark. To show the efficacy and influence of the multi-objective genetic algorithm optimization in the proposed scheme, we compare our results with those obtained using a pure DWT watermarking scheme, as described by, and with those obtained using the SVD-LWT watermarking scheme, albeit with a single scaling factor. It is common practice to abbreviate the names of algorithms like PDWT and SSF. The LH3 sub band is used in the embedding process, whereas the l = 3 sub band is used in the lifting wavelet transform. Careful selection of genetic algorithm parameters is required to get appropriate values for the multiple scaling factor (MSF). Size of population, chance of crossover, and chance of mutation are all independent variables.

V. RESULTS AND DISCUSSION

Table 1 contains the genetic algorithm simulation settings.

Table 1: Genetic Algorithm Setting Parameters

Control parameters	**Setting**
Population size (PS)	120
Generation number (GN)	180
Number of variables (NV = MSF)	32
Selection method	Roulette Wheel selection
Crossover type	Arithmetic crossover
Crossover probability (PC)	0.8
Mutation type	Gaussian mutation
Mutation probability (PM)	0.05

We employ multi-objective optimization to choose eight unique attacks (T = 8) to test. For each type of attack, we've assigned a symbol; for example, SP stands for salt and pepper noise (density 0.05), GF stands for a Gaussian filter (three-dimensionality three), CR stands for cropping (1/8 center), CM stands for contrast management, SH stands for sharpening, SC stands for scaling (256 512 256), HE stands for histogram equalization, and QN stands for gray value quantization (one bit). The suggested watermarking system's resilience may be readily adjusted by changing the number of attacks (T), which in turn depends on the watermarking use case. Tests comparing the proposed scheme's stealthiness and endurance to those of the PDWT and SSF systems are summarized in Table 2.

Table 2: Imperceptibility and robustness tests

	Scheme	**NC(I, Iw)**	**NC(W, $\widehat{W}$)**	**NC(W, $\widehat{W}_i$)**							
				SP	**GF**	**CR**	**CM**	**SH**	**SC**	**HE**	**QN**
Baboon	MSF-Scheme	1.003	1.003	0.979	0.993	0.990	0.982	0.977	1.01	0.987	0.986

	SSF	0.994	1	0.839	0.789	0.982	0.889	0.912	0.919	0.965	0.962
	PDWT	0.994	0.994	0.691	0.862	0.986	0.630	0.709	0.989	0.438	0.571
Lena	MSF-Scheme	0.994	0.991	0.996	0.993	0.982	0.991	0.997	0.997	0.991	0.976
	SSF	0.994	1	0.752	0.705	0.838	0.858	0.966	0.988	0.990	0.975
	PDWT	0.994	0.994	0.619	0.862	0.980	0.638	0.670	0.994	0.591	0.627
Peppers	MSF-Scheme	0.994	1.000	0.988	0.998	0.981	0.942	0.985	1.000	0.992	0.979
	SSF	0.994	0.994	0.769	0.723	0.883	0.858	0.966	0.987	0.979	0.962
	PDWT	0.994	0.994	0.717	0.886	0.980	0.613	0.696	0.992	0.752	0.537

As can be seen in Table 2, the recommended watermarking method fares better when the optimal multiple scaling factors (MSF) are used as opposed to the more common single scaling factor (SSF). Those aforementioned experimental results prove beyond a reasonable doubt that the proposed watermarking scheme with multiple scaling factors (MSF) provides better performance in terms of imperceptibility and durability than the identical watermarking algorithm using a single scaling factor (SSF) and the PDWT approach.

VI. CONCLUSION

It is now abundantly obvious from our investigation of this state-of-the-art technology that Multi-Objective Genetic Algorithm Optimization for Image Watermarking has the potential to radically alter the means by which we protect digital material. It represents a dynamic intersection of science and art, where mathematical precision and computational intelligence come together to ensure the integrity, authenticity, and ownership of digital assets. The research in this field is ongoing, promising even more innovative solutions and broader applications in the realm of digital content protection. The results of the experiments show that the suggested system works better than the SSF and PDWT watermarking techniques. One-way hash functions are also used to address the issue of false positive detection, which is common in SVD-watermarking techniques.

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