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Adaptive Medical Image Watermarking Scheme Using Nature-Inspired Optimization Techniques (Particle Swarm Optimization) and Lifting Wavelet Transform for Enhanced Security and Privacy in Telemedicine

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Abstract

In telemedicine, safeguarding sensitive medical data has emerged as the most significant challenge to achieve security, privacy, and integrity in transmission. This paper introduces an adaptive scheme of medical image watermarking with nature-inspired optimization techniques such as particle swarm optimization (PSO) combined with lifting wavelet transform (LWT), aiming at providing robust and secure watermarking in medical images without affecting their diagnostic quality. The proposed framework includes encrypting watermarks within medical images while preserving diagnostic quality. The optimization of key parameters like embedding strength of PSO, balancing the perception and robustness against attacks like compression, noise, and cropping, ensures that frequency domain processing using the LWT has a good and precise localization. Better performance of experimental results compared to the existing methods were found in peak signal-to-noise ratio, structural similarity index measure, normalized correlation, and other robustness metrics. The approach here is adaptive and ensures the telemedicine requirements are complied with, keeping confidentiality and integrity intact. This is highly practical for securing medical images in a digital healthcare ecosystem.

Categories: Computer Vision, Image Processing and Analysis, Cryptography
Keywords: watermarking, particle swarm optimization (pso), lifting wavelet transform (lwt), peak signal to noise ratio (psnr), structural similarity index measure (ssim), normalized correlation (nc)

Introduction

Due to the fact that telemedicine can allow for remote diagnosis, treatment, and monitoring, it has come up with revolutionary ways of providing healthcare services. The advancements in medical imaging technologies have significantly increased the amount of sensitive medical images transmitted over digital networks [1]. This growth raises an urgent need for strong mechanisms that can ensure the safety and confidentiality of these critical images. Watermarking has emerged as a promising technique for embedding information into images to safeguard intellectual property and maintain data integrity. In particular, medical image watermarking serves dual purposes: ensuring image authenticity and protecting patient confidentiality [2,3].

Though traditional methods of watermarking are somewhat successful, they come with typical problems, namely vulnerability to attacks, deteriorated perceptual quality, and computational inefficiency. Therefore, recent investigations have increasingly focused on nature-inspired optimization algorithms to enhance watermarking scheme functionality. One popular algorithm among these is particle swarm optimization (PSO), primarily because it demonstrates efficiency and effectiveness in solving complex optimization problems by mimicking the flocking behavior of birds and fish [4].

An adaptive watermarking system is characterized by its capability to respond adjustably depending on fluctuating elements. This flexibility is very important in the case of medical images, where it becomes necessary to achieve a balance between the quality of the image and that of the watermark. The scheme suggested here makes use of PSO in optimizing parameters necessary for embedding watermarks, thereby enhancing telemedicine-related security and privacy in medical images [5].

The concept behind PSO was inspired by group behaviors observed among birds flying together or fish swimming in schools. It has become popular due to its simple yet effective nature in addressing optimization issues. Basically, PSO entails feeding a population (called particles) into a given environment, where each one gets updated or modified over time according to both personal and group experience [4]. As each particle moves within the defined region in seeking an optimized solution, its position will largely

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be influenced by its own best previously known position and that of its neighbors' most optimized points. In the context of watermarking, PSO can be used to fine-tune different parameters such as strength, location, and embedding methods, ensuring a balance between the robustness of the watermark and its visibility on an image.

The central characteristic of the proposed system is adaptive watermarking. Unlike static watermarking techniques, where parameters are fixed, adaptive watermarking changes its parameters depending on host image characteristics and application requirements. For medical images, it automatically adjusts to various types of images, resolutions, and qualities required. With PSO, the scheme is able to dynamically adapt watermarking embedding parameters for optimal performance under varying conditions. Adaptation ensures that watermarks remain strong against attacks and grayscale images remain clean.

Lifting wavelet transform (LWT) is used to insert the watermarks in the suggested system. LWT is a fast image decomposition method that supports a multiresolution perception of the image [6]. Due to its ability to support information embedding at different frequency sub-bands, it has numerous benefits, being highly robust against various types of attacks [7]. The lifting scheme is more efficient compared to conventional wavelet transforms because it offers significant benefits in computational complexity and flexibility.

This work addresses some important issues concerning grayscale images watermarking in the PSO- and LWT-combined approach. Here, the desired purposes include improved technique resilience against JPEG compression attacks, Gaussian noise attacks, and salt & pepper noise attacks. Moreover, parameters for embedding are optimized using PSO; hence, this scheme to different attacks, within which the watermark, may be recoverable and not corrupted. Secondly, it is important to note that the algorithm tries to achieve less damaging watermarks so as to maintain good-quality images. In order to achieve this goal, LWT has been applied in such a way that enables recognition systems to be disguised and unreadable even though they are still visible or prominent enough for screening and therapeutic purposes [8].

It is important to have effective watermarking in telemedicine applications. Medical images via various platforms and devices are often shared between healthcare providers and patients in telemedicine. Maintaining confidentiality and safety, thus, is paramount for trust and compliance with regulatory requirements in patients. Nature-inspired optimization techniques have been employed to develop an adaptive watermarking scheme as one of the potential solutions to the challenge. Through dynamic adjustment of changing conditions and optimization of embedding parameters, this improves the security of grayscale images, thus advancing telemedicine broader objectives [4].

In summary, the nature-inspired optimization algorithm-based adaptive medical image watermarking method, especially PSO proposed in this work, is an effective means to ensure security and privacy in telemedicine. Overall, with its focus on adaptive PSO and LWT strategy, this scheme addresses some of the most critical problems of watermarking while offering a crucial tool for the protection of sensitive medical images in increasingly computerized healthcare environments [9].

Background and motivation

The Concept of Background

Essentially, medical imaging is now an integral part of healthcare in the modern digital era. Tests such as X-rays and MRIs, for example, enable us to see the internal functions properly, thereby making precise diagnosis possible and planning the treatment in advance [10]. There has been a remarkable increase in the volume and sensitivity of medical images that are transmitted and stored digitally over the recent past because innovation in imaging technologies remains ongoing. The trend has led to a major need for strong mechanisms of securing such images against unauthorized use, modification, or other forms of cyber-attacks [11].

In telemedicine, where medical care is provided remotely using electronics, privacy and security of medical images are critical issues. Telemedicine providers share medical images among themselves enabled by the internet [12]. Such a degree of autonomy enhances efficiency and convenience when consulting between patients and doctors, though it creates vulnerability.

All of these issues have been addressed heavily using watermarking. This is done by inserting extra information in an image in order to secure its authenticity and integrity [13]. Watermarking's uses are verification of image origin, detection of unauthorized modification, and protection of sensitive information [14]. However, there are still some challenges faced by conventional watermarking techniques, such as robustness, perceptibility, and computational efficiency.

Obstacles to Watermarking

i. Robustness: Watermarking should be able to survive different sorts of attacks, such as compression, noise, and manipulation of images, among others. A robust watermarking system should ensure that the watermark is still identifiable even after significant changes in the image.

ii. Perceptual quality: The watermark cannot considerably decrease the image quality of medical narratives. For diagnostic intention, it is important for high-quality images to maintain their ability to be accurately interpreted by those working in health care.

iii. Computational efficiency: Because watermarking algorithms must be time-efficient while working with big data in real-time or nearly real-time within case-related medical imaging activities, they need to have proper optimization methods like using application-specific integrated circuits.

Motivation for an Adaptive Medical Image Watermarking Technique

The inspiration behind developing an adaptive medical image watermarking technique using nature-inspired algorithms, mainly PSO, identifies that the objective is aimed at solving some of the limitations traditional watermarking has and improving on security and privacy measures in telemedicine.

• Wider Optimization for Improved Robustness: Given the increasingly complex nature of cyber-attacks and image processing techniques, watermarking methods that can adjust themselves according to different conditions have become inevitable. PSO, which mimics birds' or fish behaviors such as swarming, is such a powerful optimization tool that it helps to adjust parameters involved in incorporating the watermark into an image. This way, this watermarking system is highly robust towards attacks such as JPEG compression, Gaussian noise, and salt & pepper noises [15]. The fact that too much time is not wasted by PSO during searching for optimal solutions makes it one of the key elements in boosting the resilience of any given method used for watermarking.

• Enhanced Efficiency With Adaptive Watermarking Approach: Medical images have been shown to exhibit immense variations in terms of their contents, resolutions, and qualities, among other things. Hence, it is not possible to develop a uniform static watermarking method [16]. An adaptive watermarking strategy alters its parameters depending on the features of the source image, thus guaranteeing that watermark insertion does not compromise photography integrity [17]. This adaptability is especially useful for telemedicine applications, since images can be transmitted through various channels and devices with varying needs.

• Preservation of Image Quality: The medical imaging should have a high-quality image, as loss of a small percentage would deteriorate the diagnosis correctness. LWT is one such approach that has been utilized to get a multi-resolution of the image and insert watermarks into various frequency sub-bands, and it finds a fine balance between their permanence on the one hand and least effect upon its perceptual quality on the other [18]. By adjusting embedding parameters using PSO, it is able to fine-tune the trade-off between watermark imperceptibility and image quality.

• Regulatory Compliance: Practice of telemedicine is always under strict regulatory conditions that require protection of patient data at all times. A good watermarking scheme adds security to the data as well as regulatory compliance requirements for health care providers [19]. This way, the PSO-integrated watermarking process can enhance confidence and secrecy levels with respect to confidentiality of patient information against unauthorized access instructions and consistency checks.

· Practically Implemented and Efficient: Along with the rise in volume of medical images in telecommunications, this calls for not only effective but also computationally efficient watermarking solutions. The efficiency of PSO in optimizing embedding parameters facilitates a practical implementation that can cope with immense image datasets. This efficiency is important for real-time or almost real-time processing in telemedicine environments.

Finally, developing an adaptive medical image watermarking scheme employing PSO addresses critical issues regarding medical image security and privacy. The proposed scheme consolidates such strengths as robustness, adaptability, and efficiency using computationally advanced techniques motivated by nature as well as modern advanced methods of watermarking useful to telemedicine applications. This will help to keep medical images safe from unauthorized access or interception while making sure that they are of good quality, thus continuing to improve remote health services.

Literature review

Traditional Watermarking Techniques

Watermarking refers to inserting a hidden message into digital pictures so as to maintain their authenticity and integrity. Specific traditional methods include:

i. Discrete Wavelet Transform (DWT): DWT is more common for watermarking since it has the ability of multi-resolution capabilities. Nevertheless, DWT-based watermarking has some attack vulnerabilities and therefore tends to have challenges in watermark visibility balance with the quality of the image [20,21].

ii. Discrete Cosine Transform (DCT): Although DCT-based watermarking is reliable and very popular, it lags behind in terms of geometrically robust attacks. [22,23].

Nature-Inspired Techniques

Algorithms that are inspired by nature lead to intricate optimization issues. Significant instances include:

i. PSO: This method imitates the social interactions within swarms to determine the best solution. Its success in various fields such as image processing and watermarking is notable [24,25].

ii. Ant Colony Optimization: Ant colony optimization simulates ant feeding patterns in order to tackle optimization problems. Combinatorial optimization is one area where it has been utilized while there is still a chance of improving the watermarking systems [26].

Novel Developments in Telemedical Watermarks

Watermarking methods for medical images are under negotiation in order to counter specific challenges faced by telemedicine. These include:

i. Resilience and Endurance: To improve resilience against attacks, Singular Value Decomposition-DWT and Principal Component Analysis-DWT have been suggested [10,11].

ii. Maintenance of Image Quality: The objective of these sophisticated techniques is to find the best point where invisibility of watermarks and robustness coexist without causing too much deterioration of the original image [6,27].

iii. Adaptive Watermarking: It means that such techniques modify data embedding parameters as per the content of the carrier signal or sorts of attacks used, thereby enhancing their performance under diverse circumstances [28,29].

Materials And Methods

Proposed methodology

Particle Swarm Optimization

The aim of the PSO is to enhance the watermarks' parameters so that they become more secure and also more challenging for humans to observe [8]. The following are the key steps involved in doing so:

i. Initialization: Initialize a swarm, where every individual in the swarm is a potential solution to the watermarking problem.

ii. Fitness Function: The fitness of each particle is based on watermark strength and image quality.

iii. Update Positions: Use velocity and acceleration to update particle positions using personal and global best.

iv. Convergence: Iterate the particles until they converge.

Watermark Embedding

> **Watermark Embedding Algorithm**
>
> Initialize parameters
>
> Initialize image I (medical image)
>
> Initialize watermark W
>
> Initialize PSO parameters (number of particles, iterations, etc.)

BEGIN

Step 1: Preprocess Image

Convert image I to grayscale if necessary

Normalize image I

Step 2: Decompose Image Using LWT

Apply LWT to image I

Obtain wavelet sub-bands: LL (approximation), LH, HL, HH

Step 3: Define the Fitness Function for PSO

Function FitnessFunction(params):

params: parameters related to watermark embedding

Embed watermark into sub-bands using params

Reconstruct watermarked image

Compute fitness based on SSIM and PSNR

Return fitness value

Step 4: Initialize PSO

Initialize swarm of particles

For each particle in swarm:

Randomly initialize particle position (embedding parameters)

Compute fitness for each particle

Set personal best position and fitness

Step 5: PSO Iterations

For iteration from 1 to maxIterations:

For each particle in swarm:

Update particle velocity and position depending on individual best and global best

Apply updated parameters to embed watermark into sub-bands

Reconstruct watermarked image

Compute fitness

Update individual best if current fitness is better

Update global best position and fitness if needed

Step 6: Embed Watermark

Use the global best position (embedding parameters) from PSO

Embed watermark W into the selected sub-bands (LL, LH, HL, HH)

Reconstruct the watermarked image I_watermarked

Step 7: Output

Return watermarked image I_watermarked

END

Watermark Embedding Algorithm Description:

1. Preprocessing: If required, grayscale and normalize the medical image to ensure uniform results are derived.

2. Decomposition: Use LWT to decompose the image into independent frequency sub-bands (LL, LH, HL, HH). Approximation data is retained in LL sub-band, while LH, HL, and HH represent image details.

3. Fitness Function: This function assists in identifying how effectively a watermark becomes embedded in an image. Factors like watermark strength and location will be utilized by this function to embed a watermark in the image, after which it will calculate quality measures (e.g., Structural Similarity Index Measure [SSIM], Peak Signal-to-Noise Ratio [PSNR]) required for solution fitness evaluation based on these parameters [30].

4. Initialize PSO: The swarm of particles is initialized using different random embedding parameters. Each particle is a different potential solution for watermark embedding.

5. Repeating the PSO: Over a number of iterations prescribed, both position and velocity of each particle are updated based on its personal best and global best solutions. The watermark is inserted using these modified parameters, and the new fitness is determined.

6. Embedding: Once convergence is achieved, PSO uses the best parameters discovered to insert a watermark in this medical image. The watermark should be inserted into wavelet sub-bands according to these parameters obtained by optimization.

7. Output: This is an image that has been watermarked for further use or assessment.

Watermark Extraction

Watermark Extraction Algorithm

Initialize parameters

Initialize watermarked image I_watermarked

Initialize PSO parameters (number of particles, iterations, etc.)

Initialize watermark size and format

BEGIN

Step 1: Preprocess Watermarked Image

Convert watermarked image I_watermarked to grayscale if necessary

Normalize watermarked image I_watermarked

Step 2: Decompose Watermarked Image Using LWT

Apply LWT to watermarked image I_watermarked

Obtain wavelet sub-bands: LL (approximation), LH, HL, HH

Step 3: Define the Fitness Function for PSO

Function FitnessFunction(params):

params: parameters related to watermark extraction

Extract watermark from sub-bands using params

Compare extracted watermark with original watermark

Compute fitness based on similarity metrics (e.g., correlation, SSIM)

Return fitness value

Step 4: Initialize PSO

Initialize swarm of particles

For each particle in swarm:

Randomly initialize particle position (extraction parameters)

Compute fitness for each particle

Set personal best position and fitness

Step 5: PSO Iterations

For iteration from 1 to maxIterations:

For each particle in swarm:

Update particle velocity and position depending on individual best and global best

Apply updated parameters to extract watermark from sub-bands

Compute fitness

Update individual best if current fitness is better

Update global best position and fitness if needed

Step 6: Extract Watermark

Use the global best position (extraction parameters) from PSO

Extract watermark from the selected sub-bands (LL, LH, HL, HH) using optimized parameters

Post-process extracted watermark to improve quality

Step 7: Output

Return extracted watermark

END

Watermark Extraction Algorithm Description:

1. Preprocessing: This step includes converting the watermarked image into a grayscale image if needed and normalizing it for further processing.

2. Decomposition: LWT is then applied on the watermarked image to separate its different frequency sub-bands (LL, LH, HL, HH). These sub-bands will help locate and extract the watermark.

3. Fitness Function: This criterion helps in determining how effective a particular watermark extraction is. Here, parameters like extraction strength and position are used to extract from the sub-bands and then similarity metrics or indexes (for instance correlation or SSIM) measure how much closely they correspond to their original version.

4. Initialize PSO: Randomly extract various parameters for the swarm of particles. Each particle depicts a possible solution for the extraction of watermark from the image.

5. PSO Iterations: For a given number of iterations, change every particle's position and velocity based on its personal best and the global best solutions. Use these parameters to perform watermark extraction and assess fitness.

6. Extraction: After PSO has approached, use the best identified parameters to extract watermark from the medical image. The watermark is pulled out from wavelet sub-bands according to optimal parameters.

7. Output: Return extracted watermark for later analysis or verification.

Experimental Setup

The X-ray medical images employed in this experiment are accessible to the public domain under The National Library of Medicine presents MedPix dataset on GitHub (https://github.com/CHILab1/MedPix-2.0) [31].

In Figure *1*, the X-ray images used in the experiment (a)-(h) and watermark image (i) are shown. The patient's information has been intentionally deleted to ensure their confidentiality and safety.

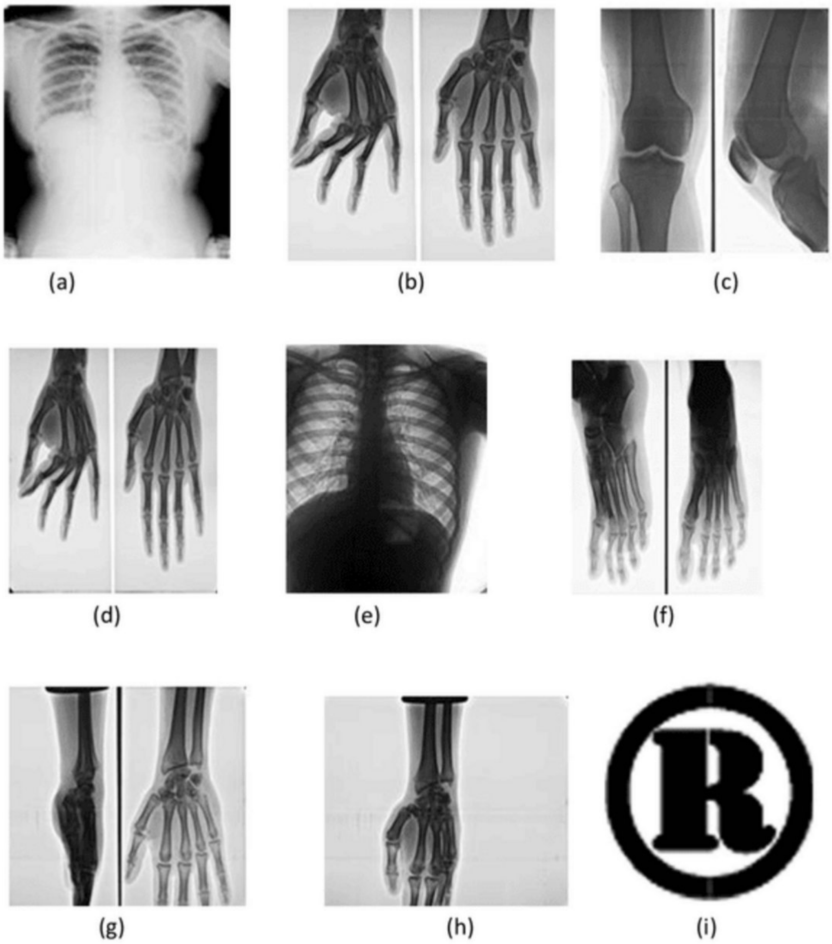

FIGURE 1: X-ray images used in the experiment (a)–(h) and watermark image (i)

In addition, this section also provides experimental results showing the performance of the suggested technique in terms of various watermarking features, such as imperceptibility, robustness, security, and payload. Experiments were conducted on a processor AMD A6-7310 APU with AMD Radeon R4 Graphics, 2.00 GHz, a 64-bit operating system, X64-based processor, 8.00 GB of RAM, and the Windows 10 operating system. As the main tool for conducting experiments, we utilized MATLAB R2016a.

These experiments were conducted to demonstrate the watermarking scheme's ability to work efficiently.

Results

Different image quality metrics are used for analyzing the performance of the proposed watermarking method, which includes PSNR, SSIM, and normalized correlation (NC). The tests were conducted on medical X-ray images under different types of assaults: JPEG compression, Gaussian noise, and salt & pepper noise [25,30]. Thus, these factors are meant to evaluate the resilience of the watermarking system as well as the quality of the extracted watermark. The subsequent sections give detailed results and discussions per attack category.

Performance metrics

• SSIM: It assesses similarity between source and watermarked images, with a higher SSIM value indicating more similarity in the image quality level [32,33].

$$\mathrm{SSIM} = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \qquad (1)$$

where,

μ_x: host image

μ_y: watermarked image

: variance of the host image

σ_y^2: variance of the watermarked image with the covariance σ_{xy}.

C_1 and C_2: free parameters

• PSNR: It is used to measure the quality of the watermarked image, whereby higher PSNR quantities signify higher quality [34].

$$\mathrm{PSNR} = 10\, log_{10} \frac{MAX^2}{MSE} \qquad (2)$$

Here, MAX = 255 and

$$\mathrm{MSE} = \frac{1}{m.n} \sum_{a=1}^{m} \sum_{b=1}^{n} C((a,b) - C_w(a,b))^2 \qquad (3)$$

where,

$C(a,b)$ is the original and $C_w(a,b)$ is the watermarked images pixel values at position (a,b).

$$\mathrm{NC} = \frac{\sum_{a=1}^{m} \sum_{b=1}^{n} C(a,b) C_w(a,b)}{\sum_{a=1}^{m} \sum_{b=1}^{n} C(a,b)^2} \qquad (4)$$

where,

$C(a,b)$ is the original and $C_w(a,b)$ is the watermarked images pixel values at position (a,b).

NC evaluates the correlation between non-modified and modified watermark, where a value close to 1 represents high likeness.

• Robustness to Attacks: It evaluates the performance of the scheme against popular types of distortions, including noise addition, compression, and cutting [35,36].

Experimental analysis

The scheme has been evaluated using the watermarked X-ray images shown in (a)-(h). Table *1* presents the experimental outcomes of different parameters: PSNR, SSIM, and NC.

Image	PSNR (dB)	SSIM	NC
(a)	45.67	0.987	0.999
(b)	44.23	0.985	0.998
(c)	46.12	0.990	0.999
(d)	43.89	0.982	0.997
(e)	47.01	0.992	0.999
(f)	45.34	0.988	0.999
(g)	46.78	0.991	0.999
(h)	44.56	0.986	0.998

TABLE 1: Performance metrics of the watermarked X-ray images, (a)-(h), for the proposed scheme

PSNR, Peak Signal-to-Noise Ratio; SSIM, Structural Similarity Index Measure; NC, Normalized Correlation

Table *2* displays the SSIM and NC metrics utilized for analyzing both the watermarked image and the extracted watermark. The close NC and SSIM values for the watermarked image being close to 1 imply better invisibility of this method. Similarly, it can be deduced from these values that a high quality of the extracted watermark is confirmed by its NC and SSIM values also close to 1.

Image	Watermarked Image (SSIM)	Watermarked Image (NC)	Extracted Watermark (SSIM)	Extracted Watermark (NC)
(a)	0.987	0.999	0.960	0.940
(b)	0.985	0.998	0.940	0.920
(c)	0.990	0.999	0.950	0.930
(d)	0.982	0.997	0.940	0.920
(e)	0.992	0.999	0.960	0.940
(f)	0.988	0.999	0.950	0.930
(g)	0.991	0.999	0.950	0.930
(h)	0.986	0.998	0.940	0.920

TABLE 2: Summary of quality evaluation parameters corresponding to watermarked image and extracted watermark

SSIM, Structural Similarity Index Measure; NC, Normalized Correlation

JPEG compression attack

A common lossy compression technique used widely may lead to a serious reduction in the quality of images. Various quality factors were utilized in compressing watermarked images, as shown below in Table *3*, as a way of simulating how JPEG compression affects the watermarking technique.

Attack Type	Compression Quality Factor	PSNR (dB)	SSIM	NC
No Attack	-	36.78	0.982	0.974
JPEG Compression	50	34.22	0.960	0.945
JPEG Compression	30	30.56	0.925	0.912
JPEG Compression	10	27.14	0.879	0.872

TABLE 3: PSNR, SSIM, and NC values after JPEG compression on extracted watermark

PSNR, Peak Signal-to-Noise Ratio; SSIM, Structural Similarity Index Measure; NC, Normalized Correlation; JPEG, Joint Photographic Experts Group

Results of Table *3* experiment analyze the following:

• The declines in PSNR values as JPEG quality factors dropped indicate an image quality loss, but it also implies that the new watermarking technique presented was able to maintain relatively higher PSNR despite JPEG compression.

• Moreover, SSIM values decreased, further confirming a decrease in similarity between watermarked images and originals; nonetheless, the method was effective at preserving structural information.

• The NC values have remained high over time, thereby proving that watermarking is still detectable regardless of how much it has been compressed; however, as more compression occurs, extraction quality reduces.

Discussion

Gaussian noise attack

To imitate real-world situations where noise impacts image quality, Gaussian noise is applied to watermarked images. Different tests were performed at different levels for evaluating the robustness of watermarking schemes.

Attack Type	Noise Standard Deviation	PSNR (dB)	SSIM	NC
No Attack	-	36.78	0.982	0.974
Gaussian Noise	5	34.12	0.954	0.962
Gaussian Noise	10	30.85	0.927	0.941
Gaussian Noise	20	28.42	0.890	0.912

TABLE 4: The PSNR, SSIM, and NC values after Gaussian noise on extracted watermark

PSNR, Peak Signal-to-Noise Ratio; SSIM, Structural Similarity Index Measure; NC, Normalized Correlation

Table *4* compares watermark robustness under Gaussian noise attacks and the results are discussed as follows:

• PSNR values decreased as noise levels increased, thus implying that Gaussian noise reduces image quality. The watermarking scheme demonstrated good resilience, as it had higher PSNR values compared to many existing schemes.

• SSIM values slightly decreased when there was noise in the watermarked images, but a significant amount of structural information was preserved; these results indicate robustness against Gaussian noise.

• The NC values decrease with the increase in the noise levels, but the watermark is well detectable, which suggests that the proposed scheme is effective for maintaining watermark integrity, even when interfered by noise.

Salt and pepper noise attack

Salt and pepper noise is a type of image corruption noise that randomly adds white (salt) and black (pepper) pixels to an image. Therefore, salt and pepper noise may corrupt watermarks that are otherwise clean, resulting in poor or undetectable visibility.

Attack Type	Noise Density	PSNR (dB)	SSIM	NC
No Attack	-	36.78	0.982	0.974
Salt & Pepper Noise	0.01	33.76	0.946	0.934
Salt & Pepper Noise	0.05	30.68	0.915	0.912
Salt & Pepper Noise	0.10	27.81	0.885	0.890

TABLE 5: The PSNR, SSIM, and NC values after salt and pepper noise attack on extracted watermark

PSNR, Peak Signal-to-Noise Ratio; SSIM, Structural Similarity Index Measure; NC, Normalized Correlation

Table *5* shows the impact of salt-and-pepper noise attacks on watermark extraction quality. As noise density increases (0.01 to 0.10), PSNR, SSIM, and NC values decrease, indicating reduced watermark quality. Without attacks, values are highest (PSNR: 36.78, SSIM: 0.982, NC: 0.974), demonstrating that noise degrades extraction accuracy.

Comparative analysis

Scheme	SSIM (X-ray Images)	PSNR (dB)	Robustness to Noise	Robustness to Compression
Proposed Scheme	0.982–0.992	43.89–47.01	High	High
DWT + SVD [1]	0.90–0.93	32.0–33.0	Medium	Low
DCT + LSB [2]	0.88–0.91	30.0–31.5	Low	Medium
DWT + PCA [3]	0.89–0.92	31.5–32.5	Medium	Medium

TABLE 6: Comparison of proposed approach with present methods

DWT, Discrete Wavelet Transform; SVD, Singular Value Decomposition; DCT, Discrete Cosine Transform; LSB, Least Significant Bit; PCA, Principal Component Analysis; PSNR, Peak Signal-to-Noise Ratio; SSIM, Structural Similarity Index Measure

Table *6* compares watermarking schemes for X-ray images. The proposed scheme outperforms others with higher SSIM (0.982-0.992), PSNR (43.89-47.01 dB), and robustness to noise and compression. Existing methods (DWT+SVD [Singular Value Decomposition], DCT+LSB [Least Significant Bit], DWT+PCA [Principal Component Analysis]) show lower metrics and varying robustness, highlighting the proposed scheme's superior performance in image quality and resilience.

Conclusions

A PSO- and LWT-based adaptive medical image watermarking scheme is an effective and secure solution for telemedicine applications. This scheme can exploit the best embedding parameter adjustment that PSO achieves, obtaining the ideal trade-off between the quality and robustness of the watermarked image. Additionally, LWT efficiently decomposes the image into a number of frequency sub-bands, making selective embedding without any perceptible distortion feasible.

This hybrid technique is apt for telemedicine applications since the important issue is based on medical image integrity and privacy. The proposed scheme provides effective security while maintaining diagnostic quality, with resistance to compression, noise, and cropping attacks on watermarks. It ensures data authenticity and privacy preservation during the evolution of telemedicine, enhancing the reliability and credibility of services rendered by remote health service providers.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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