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Maintaining the Integrity and Authenticity of Medical Images Using Integer Wavelet Transform and Practical Swarm Optimisation Technique

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الحفاظ على سلامة وأصالة الصور الطبية باستخدام تقنية تحويل الموجة الصحيحة وتقنية أسراب العناصر المحسنة

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Abstract:
Significant advances in health care technology, especially in medical imaging, have profoundly altered the field. Digital tools such as radiography, telemedicine, and Picture Archiving and Communication Systems (PACS) have heightened the need for robust image security measures. Medical image security attempts to safeguard the accuracy and legitimacy of pictures. Integrity entails avoiding the possibility of tampering, whereas authenticity verifies the authenticity of images. The absence of these can lead to inaccurate diagnoses and inappropriate treatments. The primary objective of the work is to explore the efficacy and benefits of the Integer Wavelet Transform (IWT) and the Practical Swarm Optimisation (PSO) technique for protecting the integrity and authenticity of digital medical images. The research has two key aims. Firstly, it investigates the effectiveness of PSO-determined IWT coefficients in digital image watermarking. Secondly, it illustrates the authentication scenario using medical images, incorporating patient data and encrypted input into watermarking schemes. A normalised correlation coefficient (NCC) quantifies the similarity in recovered images, serving as the objective function in (PSO). The experimental results in the form of the time-frequency representation of the decomposed image using the IWT allow the visibility of the integrity signature on the original medical image. The proposed watermarking technique based on the integer wavelet transform and practical swarm optimisation scheme can provide a robust watermarking technique in the top two frequency bands and maintain the fidelity of the original image.

Keywords: IWT, POS, Medical image security, Integrity, Authenticity.

الملخص
لقد أدت التطورات الكبيرة في تكنولوجيا الرعاية الصحية، وخاصة في التصوير الطبي، إلى تغيير عميق في هذا المجال. زادت الأدوات الرقمية على سبيل المثال: التصوير الشعاعي، والتطبيب عن بعد وأنظمة أرشفة الصور والاتصالات (PACS) من الحاجة إلى تدابير أمنية قوية للحفاظ على خصوصية الصور الطبية. يحاول أمن الصور الطبية حماية دقة الصور وشرعيتها. تستلزم النزاهة تجنب إمكانية العبث، بينما تتحقق الأصالة من صحة الصور. يمكن أن يؤدي عدم وجودها إلى تشخيصات غير دقيقة وعلاجات غير مناسبة. الهدف الأساسي من العمل هو استكشاف فعالية وفوائد تحويل موجات الأعداد الصحيحة (IWT) وتقنية أسراب العناصر المحسنة (PSO) لحماية سلامة وأصالة الصور الطبية الرقمية. البحث له هدفان رئيسيان. أولاً، يبحث في فعالية معاملات (PSO-IWT) المحددة في وضع العلامات المائية للصور الرقمية. ثانيًا، يوضح سيناريو المصادقة باستخدام الصور الطبية، ودمج بيانات المريض والمدخلات المشفرة في مخططات العلامات المائية. يحدد معامل الارتباط الطبيعي التشابه في الصور المستردة، ويعمل كدالة موضوعية في (PSO) تسمح النتائج

التجريبية في تمثيل التردد الزمني للصورة المتحللة باستخدام تحويل الموجة الصغيرة الصحيحة برؤية توقيع التكامل على الصورة الطبية الأصلية. يمكن أن توفر تقنية وضع العلامات المائية المقترحة بناءً على تحويل موجات الأعداد الصحيحة ومخطط تحسين أسراب العناصر من وضع علامات مائية قوية في النطاقين الترددين العلويين والحفاظ على دقة الصورة الأصلية.

الكلمات المفتاحية: تحويل موجات الصحيحة، تقنية أسراب العناصر المحسنة، أمان الصورة الطبية، النزاهة، الأصالة.

1. Introduction:

Medical images are proof of the patient's pathological state and are accordingly core in patient care. It is crucial that the received data is not only accurate but totally trustable. Errors can have terrifying, lethal consequences. With the advent of digital imaging technologies, it has become feasible to transmit and distribute medical images digitally. Due to its ease of accessibility, medical images are frequently manipulated digitally [1]. There is a notable benefit of digitally grading X-ray images. The outcomes offer high computerised proficiency in detecting diseases in the chest X-ray images. Nevertheless, the digital processing of X-rays is simple, accelerating their fabrication. Patients can utilise this to make false claims against hospital staff. It is feasible for anyone to carry out such manipulation since they are in JPEG format [2].

A wide array of processed medical images, not only in JPEG format but also in downloadable text files. Sophisticated modifications of these images are feasible. Hence, there is broad exploratory operation when transmitting JPEG images. A few images probably become corrupted [3]. To validate image integrity, a secure scheme is required that can be implemented on a transmitted image. It is therefore a proposed medical image interaction-based authentication scheme, using the Integer Wavelet Transform along with a more practical modification of the Swarm Optimisation technique.

there are three specific sub-goals in this research. Firstly, to analyse the effectiveness of the PSO-selected coefficients of IWT and to study the recovery of the digital watermark of the test images. A set of mono-resolution approaches, along with a contrary scenario of the cooperation of a multi-resolution watermarking strategy, is explored in both direct and inverse modes. Toward the multi-resolution objective, three single-resolution approaches are compared to IWT watermarking strategy [8, 10, 12]. The digital images are decomposed into critical sub-bands by the Integer Wavelet Transform, and the PSO is applied to determine the exact coefficients in the low-pass band of the cubic resizing procedure. As there is an increasing number of clinical settings storing their data in digital form, it is recognised that there is a parallel demand for methods, which should ensure the reliability and trust of all of this data. One such method is digital watermarking. Transforms most commonly used in the medical image domain are Discrete Cosine Transform DCT and Discrete Wavelet Transform DWT. On the one hand, DCT provides a good compromise between concentration, image distortions, and a high capacity for the clinical settings. On the other hand, DWT works outstandingly on the efficiency of the human visual system, and it can offer a huge range of colour possibilities with regard to the luminous power of visible light [4].This paper is organized systematically. The introduction highlights the significance of using advanced techniques such as the Integer Wavelet Transform and Practical Swarm Optimization for preserving medical image quality. Section 2 reviews relevant literature. Section 3 describes the search methodology. Section 4 explains the proposed watermarking technique. Section 5 presents experimental findings and compares them with existing methods. The last section conclusion summarizes the main points.

2. Related Study

In medical imaging, electronic watermarking techniques fall into spatial and transform domain methods. Frequency domain algorithms are particularly robust against attacks while maintaining imperceptibility and manageable computational demands. Watermark embedding modifies coefficients from frequency transformations, using techniques like discrete cosine transforms, wavelet transforms, Walsh-Hadamard transforms, and Fourier transforms [5]. Zhang et al. [6] introduced a secure system for managing electronic medical records, using advanced encryption to uphold patient confidentiality and minimise image manipulation risks. Their approach combined a homomorphic transform with redundant discrete wavelet transforms and singular value decomposition, enhanced by a two-dimensional chaotic Arnold transform, achieving significant robustness over previous methods.

Lee et al. [7] created a watermarking algorithm using the integer-to-integer wavelet transform, enhancing capacity while preserving quality. It divides the image into distinct, non-overlapping blocks for independent data embedding. Additional data is inserted into high-frequency coefficients of each block using a bit-shifting strategy. The watermark is incorporated by adjusting coefficients in the LH1, HL1, and HH1 sub-bands, essential for its integrity. A location map indicates where watermark data is embedded, directly linked to the total number of image blocks, affecting the process's efficacy and efficiency.

Rai and Singh [9] introduced a hybrid technique for digital watermarking medical images that incorporates a variety of techniques. This innovative approach merges the non-subsampled contour-let transform (NSCT), multi-level discrete wavelet transforms (DWT), and singular value decomposition (SVD) to achieve an optimal degree of imperceptibility and robustness. Additionally, it employs a 2D-logistic map-based chaotic encryption method to bolster security further.

Saber et al. [11] introduced a watermarking algorithm specifically designed for medical images, which employs the Inverse Wavelet Transform (IWT) in conjunction with hash functions and logistic mapping techniques. This method strategically segments the image into two distinct areas: the region of interest (ROI), which encompasses essential data, and the region of non-interest (RONI), which holds less critical information. By embedding confidential data within the RONI, the algorithm effectively safeguards the important details contained in the ROI.

Medical image processing is crucial in healthcare technologies, involving the conversion of pictures into digital images enhanced by filtering, amplification, or rectification. Analysis is then performed to extract significant features such as texture, statistical parameters, and morphological characteristics, which help in identifying patterns. Based on these features, the image is interpreted, leading to clinical decisions. The accuracy of these processes is essential, as decreased precision can result in misinterpretation, affecting diagnosis and treatment planning. Common applications are found in radiology and pathology, where accurate image processing is vital for effective patient care [13, 14].

Maintaining the integrity and authenticity of medical images faces many challenges, including noise, distortion, and artifacts that compromise processing results. Images can be altered by unauthorised persons or damaged during network transfer due to poor compression. Techniques like information hiding and cryptography are essential for detecting alterations through watermarks. Noise Regions of Interest (NROI) watermarking ensures authenticity verification in medical images, as NROI usually contains crucial diagnostic information. A reversible multiple blind image restoration scheme is employed to uphold integrity. Results indicate that this system effectively maintains image authenticity, utilising an integer wavelet transform for watermarking changes and enabling immunisation against specific attack types [15].

Digital watermarking embeds hidden information into a cover image, influenced by a scaling factor. The technique's effectiveness relies on this factor's value, but identifying the optimal scaling factor is difficult and demands significant experimentation, making it a tedious process for researchers. An advanced watermarking algorithm is needed to automatically determine the suitable scaling factor for each cover image, enhancing watermarking frameworks' efficiency and practicality [16]. To tackle this challenge, optimisation algorithms are employed, carefully identifying an optimal parameter that corresponds with the unique features of the cover image.

3. Research Process

This paper introduces a refined frequency domain image watermarking method using the Improved Wavelet Transform (IWT) for watermark insertion and extraction. It enhances algorithm adaptability in medical imaging by determining an appropriate scaling factor through the Particle Swarm Optimization (PSO) algorithm. The results obtained from this refined approach highlighted its ability to effectively mitigate various potential attacks, illustrating its overall robustness.

3.1 Integer Wavelet Transform

The Integer Wavelet Transform (IWT) is widely used in image processing due to its rapid data handling capability. Unlike other transforms that directly deal with pixel data, the IWT can effectively manage alterations in images caused by issues like colour distortion and noise. Its unique integer property is vital for restoring damaged data, ensuring the output quality of the image transform remains intact. This advantage is unmatched by non-integer transforms, making the IWT essential for preserving the authenticity of medical images. It is also employed in various fields, including remote sensing, restorative images, and printed documents, to maintain image authenticity [17, 10]. The fundamental operation of the Discrete Wavelet Transform (DWT) is expressed in the following equation (1).

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \qquad (1)$$

The signal transforms in three stages: splitting, predicting, and updating its individual elements, as illustrated below:

Splitting: divide the signal Φ(n) into two sets: one for odd samples and one for even samples, based on Equation (2).

$$\phi_e = (2n) \text{ and } \phi_0 = \phi(2n+1) \qquad (2)$$

Predicting: abstraction allows predictions between split samples if they're connected. Anticipated values can be found using Equation (3).

$$\Psi(n) = \phi_0(n) - Y[\phi_e(n)] \qquad (3)$$

In the recent update, even samples $\phi_e(n)$ were modified using the update operator $Updt(n)$. This modification captures the low-frequency component $\mathfrak{lfc}(n)$ through the abstract difference $\Psi(n)$, approximating the original signal $\Phi(n)$, as shown in Equation (4).

$$\mathfrak{lfc}(n) = \Phi_e(n) + Updt(G(n)) \qquad (4)$$

3.2 Practical Swarm Optimisation

Practical Swarm Optimisation (PSO) is an optimisation technique from Swarm Intelligence, inspired by the behaviour of birds or fish. It effectively enhances medical imaging applications like image processing, thresholding, and edge detection. PSO also solves combinatorial optimisation problems and serves as a training method in agriculture. Recently, it has been combined with various image transforms to enhance the integrity of medical images. Its popularity stems from its simplicity and effectiveness in navigating large search spaces, balancing trade-offs between objectives like cost vs. service quality or sensitivity vs. specificity [18].

The principles of Practical Swarm Optimisation (PSO) in this paper are explored for integrating the algorithm with the Integer Wavelet Transform (IWT). PSO involves particles, fitness calculations, and initial conditions. Particles seek optimal solutions through social interactions, akin to flocks of birds. Their velocity updates based on current speed and attractions towards their and the swarm's best solutions, leading to improved positions over iterations until the stopping criteria are met (equations 5 and 6). Combining IWT with PSO in this research has been shown in next subsection to enhance image quality, effectively preserving medical details.

$$P_{best_i}^t = x_i^* | f(x_i^*) = min_{k=1,2,\cdots,t} (\{f(x_i^k)\}) \qquad i \in \{1,2,\cdots,N\} \tag{5}$$

$$g_{best}^t = x_*^t | f(x_*^t) = min_{i=1,2,\cdots n_{k=1,2,\cdots t}} (\{f(x_i^k)\}) \tag{6}$$

Where: $P_{best_i}^t$ is the prior best position, g_{best}^tglobal best position, (i) index, (t) represents the numerical designation of the current iteration, the function (f) is the target to be minimise in optimisation, (x) is a possible soulution, (N) signifies the entirety of the particles present within the swarm.

$$v_i^{i+1} = \omega v_i^t + c_1 r_1 (P_{best_i}^t - x_i^t) + c_2 r_2 (g_{best}^t) \tag{7}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{8}$$

Where: for every fresh iteration (t+1), the equations help to modify the velocity (v) and position (x) for each unique particle (i). r_1, r_2 are random values within $(0,1)^{\text{D(space dimention)}}$, and c_1, c_2 are positional coefficients.

3.3 Integration of IWT and POS for Image Authentication

The synergistic integration of Integer Wavelet Transform (IWT) with Practical Swarm Optimisation (PSO) is proposed for enhancing the security of image authentication techniques Figure 1. The integration of IWT and PSO methodologies ensures rapid, safe and secure maintenance of image authenticity. The trade-offs among the security analysis criteria, namely, robustness, common digital attacks and "no false positive acceptance" (NFP), can be achieved for the IWT-PSO methodology.

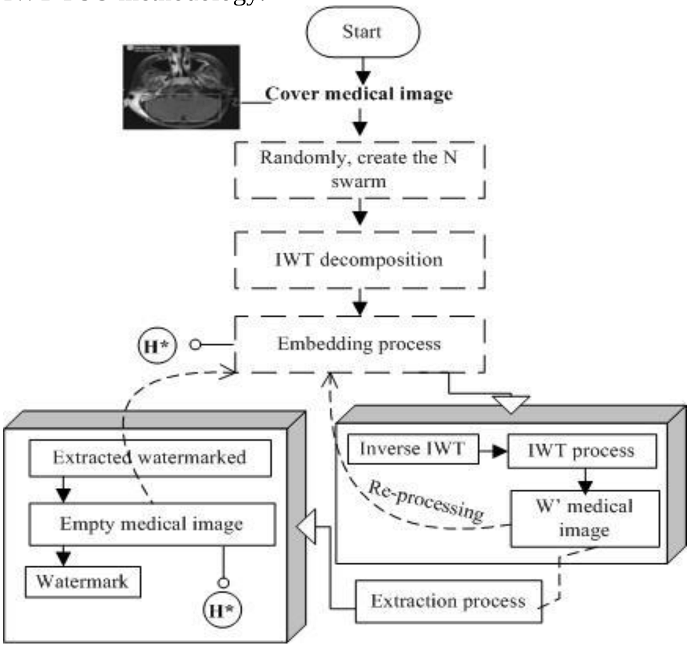


Figure (1): The integration of IWT and PSO methodologiescaption.

To maintain the security and authentication in this research, the theoretical foundation of integrating IWT and PSO is established and applied to existing methods. The IWT-PSO-based approach is detailed for standard X-ray images. Predicted results should be encourage medical imaging engineers, researchers, and stakeholders to use the IWT-PSO linkage for efficient, robust, and secure medical authentication. This forms part of the technique should be suggested to uphold image authenticity in various medical diagnoses.

This research proposes integrating IWT and PSO to ensure the authenticity of medical images. The framework consists of four stages: First, the medical image undergoes a predetermined-fold integer wavelet transform. Second, the watermark image is encrypted using a symmetric and secret key. Third, the positioning and spreading

of the watermarked image in the medical image are optimised via practical swarm optimisation (PSO). Finally, the inverse integer wavelet transform identifies the watermark. The method's efficiency is demonstrated through experiments including, robustness analysis, bit error rate assessment.
A systematic process with algorithmic validation is proposed for future research, allowing easy application of the method in medical images. The framework's model aims to improve results compared to existing watermarking systems, which play a vital role in ensuring the security of medical imaging content. Despite advancements, challenges in protecting medical image integrity and authenticity remain, prompting the establishment of the Particle Size Distribution PSD methodology [19]. This study explores the integration function to demonstrate the approach's viability and robustness. Subsequent sections will offer experimental evidence, enabling researchers to conduct their investigations.

4. Experimental Setup and Design

The performance of the proposed integration as shown in Figure 2 is validated using several commonly used benchmarks along with a comprehensive analysis and discussions of results on medical images. Special care is taken to ensure the experimental design is well-defined and that results are reproducible. The integrity and authenticity of the medical image are significant, particularly where image authentication plays a vital role in identifying the source or the modification of the image. This section presents an integration of conventional discrete wavelet transform-based image watermarking with a novel approach of using the integer wavelet transform in a practical swarm optimisation technique to maintain the integrity and authenticity of the medical image ongoing. The experimental results in the form of the time-frequency representation of the decomposed image using the integer wavelet transform allow the visibility of the integrity signature on the original medical image. The proposed watermarking technique based on the integer wavelet transform and practical swarm optimisation scheme can provide a robust watermarking technique in the top two frequency bands and maintain the fidelity of the original image.

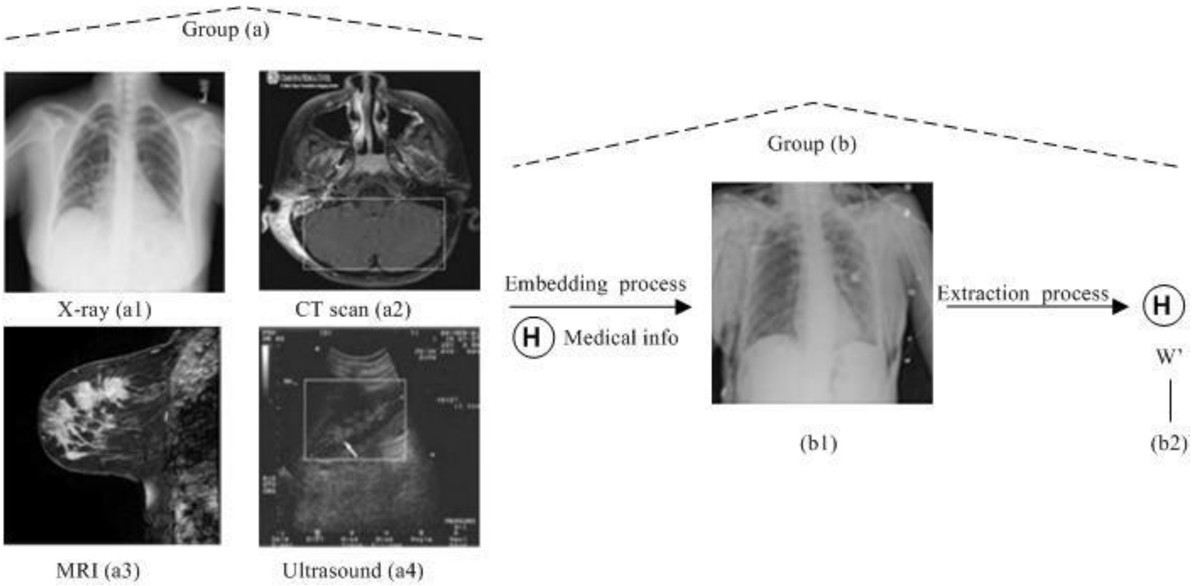


Figure (2): Group (a): Original images, Group (b): Embedding and extraction watermark image.

5. Experimental results and comparisons

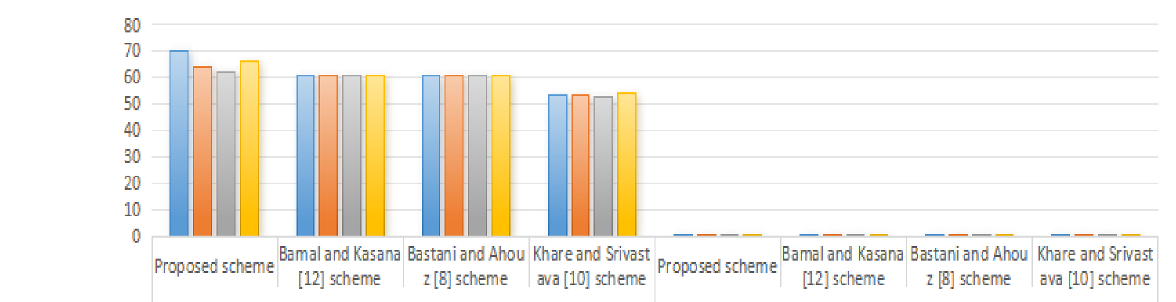
In this section, a series of experiments were carried out to showcase the effectiveness of the proposed method. The experiments utilised a diverse array of 512x512 medical images depicting various aspects of the human body, as illustrated in Figure 2 (group (a)). These images included x-rays, ultrasounds, CT scans, and MRI scans, serving as the original images for the analysis. Accompanying these was a secret watermarked image, represented in Figure 2 (group (b)). The evaluation of the proposed technique was conducted through several metrics: the peak signal-to-noise ratio (PSNR), calculated using equation 9; the normalised correlation coefficient (NCC), assessed with equation 10; and the structural similarity index (SSIM). Furthermore, to assess the robustness of the scheme, tamper detection was performed against various types of attacks. The estimation of image quality was primarily based on the calculation of the peak signal-to-noise ratio (PSNR).

$$\mathrm{PSNR}(w_k, w'_{k_w}) = 10\log_{10}\left(\frac{255^2}{(\frac{1}{m})\sum_{i=1}^{m} H_i - H'_i}\right) \tag{9}$$

Where: (m) represent the original image's dimensions, H_i the pixel values before the watermark, and H'_i the values after embedding process.

$$NC = \frac{\sum_{k=1}^{w_p * w_q} w_k * w'_k}{\sqrt{\sum_{k=1}^{w_p * w_q} w_k^2 \sum_{k=1}^{w_p * w_q} w'^2_k}} \quad (10)$$

Where: w_k is the original watermark, whereas w'_k is the extracted watermark.
The resilience of our method is evaluated on various medical images, comparing it with contemporary techniques. Interferences like JPEG compression, noise addition, filtering processes, and geometric attacks are introduced to X-rays, MRIs, CT scans, and ultrasounds. These aim to extract or alter the embedded watermarks. The quality of extracted watermarks is assessed using Structural Similarity Index (SSIM) and Normalized Cross-Correlation (NCC) values, as shown in Figures 4, 5, 6 and 7.
The results from our scheme are shown in Figure 3, comparing it to Bamal and Kasana [12], Bastani and Ahouz [8], and Khare and Srivastava [10] based on PSNR and SSIM values. Our approach significantly outperforms conventional methods, achieving average PSNR and SSIM values of (65.7020, 0.99985). In contrast, Bamal and Kasana [12] reach (60.8625, 0.9981), Bastani and Ahouz [8] record (60.87, 0.998375), while Khare and Srivastava [10] show (53.7399, 0.99815).



	PSNR				SSIM			
	Proposed scheme	Bamal and Kasana [12] scheme	Bastani and Ahouz [8] scheme	Khare and Srivastava [10] scheme	Proposed scheme	Bamal and Kasana [12] scheme	Bastani and Ahouz [8] scheme	Khare and Srivastava [10] scheme
X-ray (a1)	70.1908	60.82	60.78	53.7401	0.99985	0.9958	0.9962	0.9957
CT scan (a2)	64.3425	60.87	60.87	53.8354	0.99985	0.9996	0.9988	0.9997
MRI (a3)	62.0834	60.82	60.89	52.8559	0.99985	0.9998	0.9996	0.9998
Ultrasound (a4)	66.1914	60.94	60.94	54.5283	0.99985	0.9972	0.9989	0.9974

Figure (3): The evaluation of the proposed scheme's performance with alternatives, focusing on PSNR and SSIM metrics.

Figures 4, 5, 6, and 7 demonstrate the methodology's resilience against various attacks. The visuals show that the obtained watermark has effectively withstood most assaults, especially excelling against geometric attacks, which are among the toughest challenges in watermarking strategies.
The research examined the watermark's resilience against filtering attacks, focusing on Median and Wiener techniques with a 3 × 3 window. Findings show the extracted watermark is more resistant to filtering with this window size.

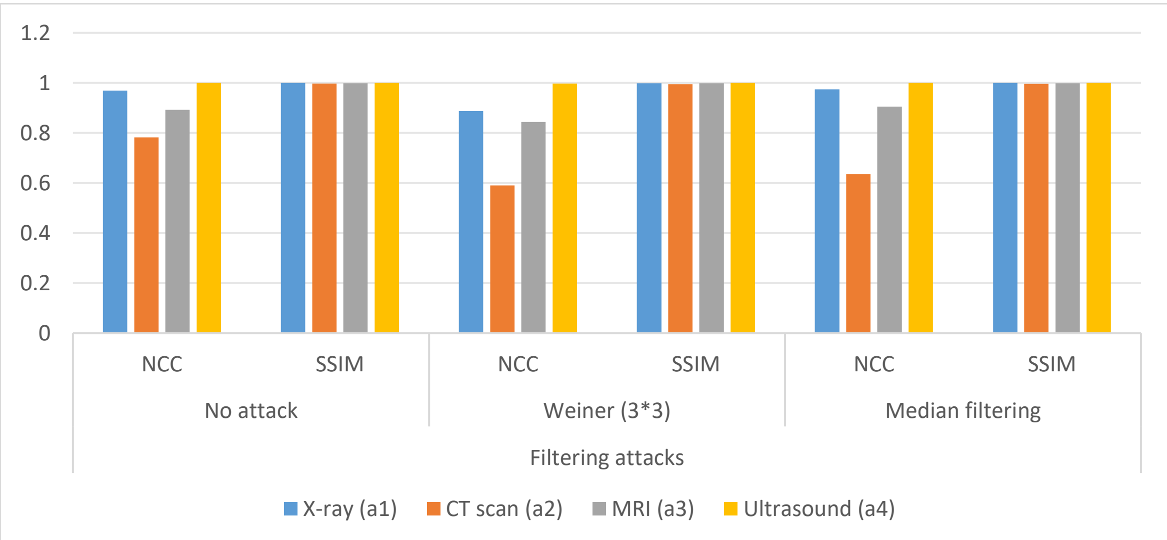


Figure (4): The effectiveness and stability of the proposed scheme under filtering attacks.

The effectiveness of a watermarking scheme is influenced by its ability to withstand noise. This study examined the impact of various noising attacks on the watermarking methodology. Figure 5 shows the retrieved watermarks with corresponding Normalized Correlation (NC) values after applying three noise types: Salt and pepper noise (0.1% and 1%), Gaussian noise (0.1% and 0.5%), and Speckle noise (0.1%). Structural Similarity Index Measure (SSIM) values ranged from 1 to 0.9999, while NC values varied from 1 to 0.9629. Generally, higher noise levels increased distortion in the watermarked images. Findings regarding robustness against noise attacks were positive.

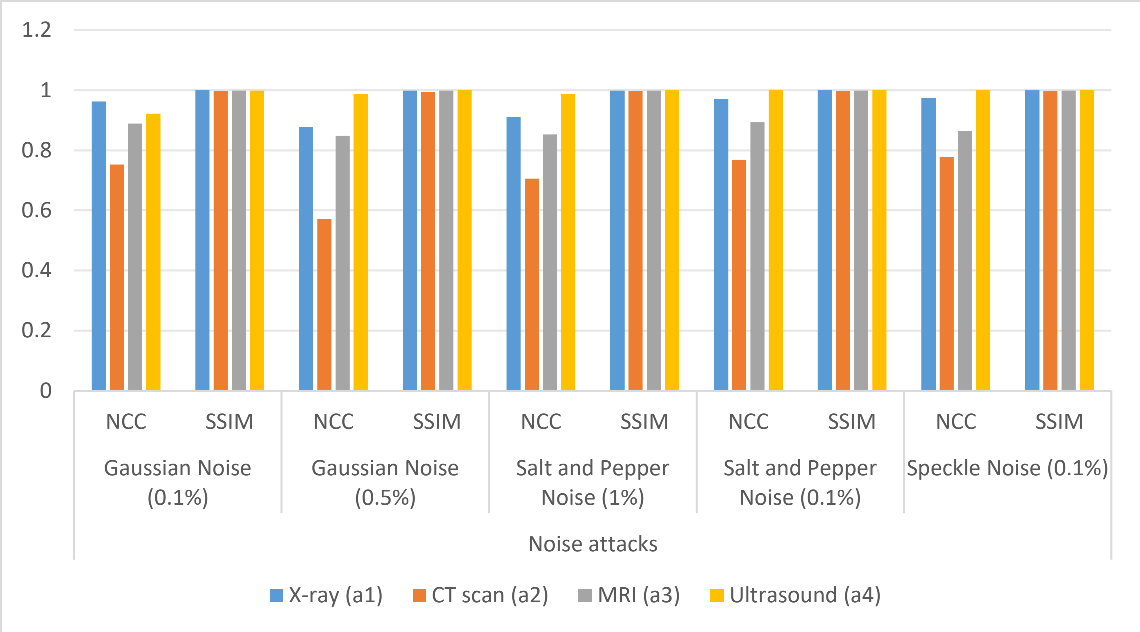


Figure (5): The effectiveness and stability of the proposed scheme under Noise attacks.

The method is evaluated concerning JPEG compression using different quality factors. This attack focuses on high-frequency image components, affecting the visual quality and pixel values of medical images. A test image experiences JPEG compression at QF values of 50 and 80. Figure 6 shows the extracted watermarks along with their Normalized Cross-Correlation (NCC) and Structural Similarity Index Measure (SSIM) values. The scheme shows strong robustness despite reduced JPEG quality factors, maintaining average NCC values above 0.9 during varying compression levels. Our approach proves resilient against these attacks, even with lower quality factors.

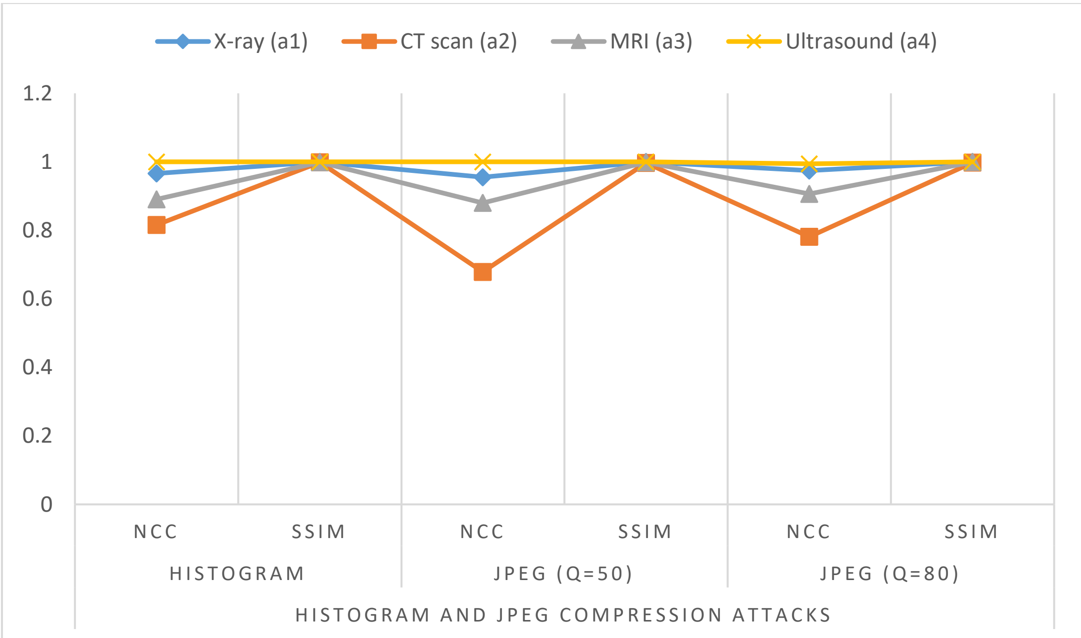


Figure (6): The effectiveness and stability of the proposed scheme under Histogram and JPEG compression attacks.

The alterations in geometric configuration disrupt the harmony within the watermarked bitstream, directly modifying the pixel orientation in the original image. Figure 7 illustrates experiments where watermarked images undergo transformations, including rotation at 1, 2, 5, and 10 degrees, and scaling adjustments of 0.5%, 0.7%, 1.2%, and 1.7%. The medical images tested include X-ray, CT scan, MRI, and Ultrasound modalities. Throughout these attacks, the average Normalized Correlation (NC) scores and Structural Similarity Index Measure (SSIM) values of the extracted watermarks exceed 0.9, indicating the effectiveness and resilience of the embedding regions against alterations.

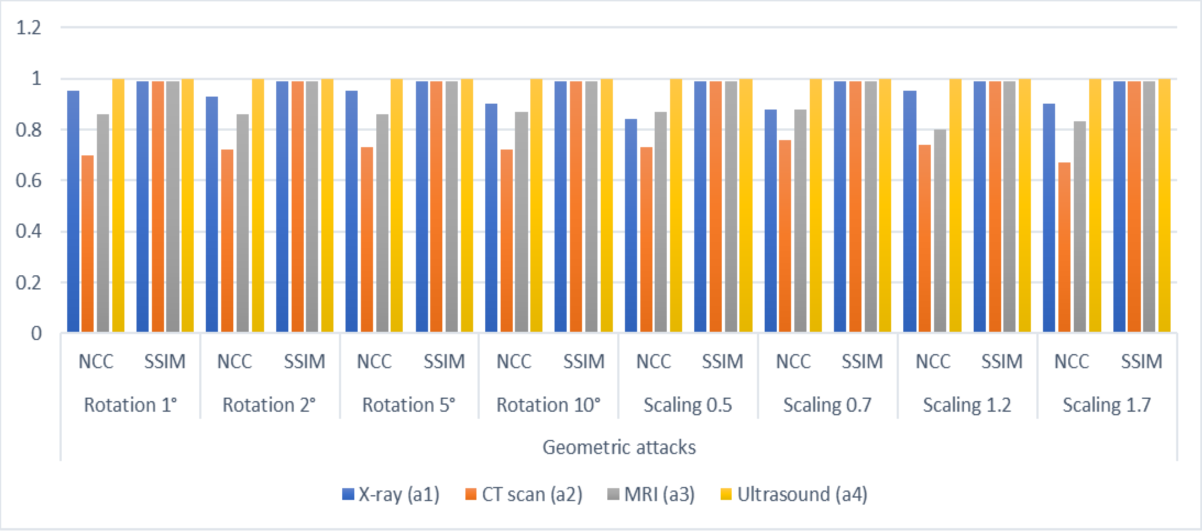


Figure (7): The effectiveness and stability of the proposed scheme under Geometric attacks.

6. Conclusion and Future Directions

This paper presents a refined digital watermarking approach tailored specifically for medical images, utilizing the Integer Wavelet Transform (IWT) during the embedding and extraction stages. The IWT is particularly advantageous for applications that require lossless data, making it exceptionally well-suited for maintaining the integrity of medical images. In addition, the method incorporates Particle Swarm Optimization (PSO) to identify the most effective scaling factor, enhancing the versatility of the scheme to accommodate images from different modalities. Experimental findings indicate that this innovative approach surpasses comparable methods in measures of both imperceptibility and robustness. This finding highlights the potential of artificial intelligence to enhance service delivery in healthcare settings. As healthcare systems face increasing demands and challenges, the integration of AI technologies can provide innovative solutions that improve patient outcomes and streamline operational processes.

Summary of Findings

Digital images can be easily modified without visible traces, with medical image forgery becoming more common due to advanced editing tools. Attackers can manipulate medical diagnoses for profit, making forgery detection essential to maintain the credibility of medical images. The proposed solution employs integer wavelet transform (IWT) and practical swarm optimisation (PSO) to medical images. The medical images is watermarked with credential information. The technique can detect, and allows retrieval of watermark information. Experiments demonstrate that this method surpasses older techniques in precision and robustness, while not compromising diagnostic ability. Thus, watermarking in the medical images enhances the credibility and authenticity of diagnostic results [13].

Potential Areas for Future Research

Research on joint watermarking and unfolding suggests considering the evolution of this paradigm. Results indicate that using the Integer Wavelet Transform can be beneficial. Further investigation could explore other transforms like the Integer Wavelet Packet Transform and incorporate optimisation techniques for watermark unfolding, such as Enhanced Weighted Histogram Equalisation and Practical Swarm Optimisation.

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