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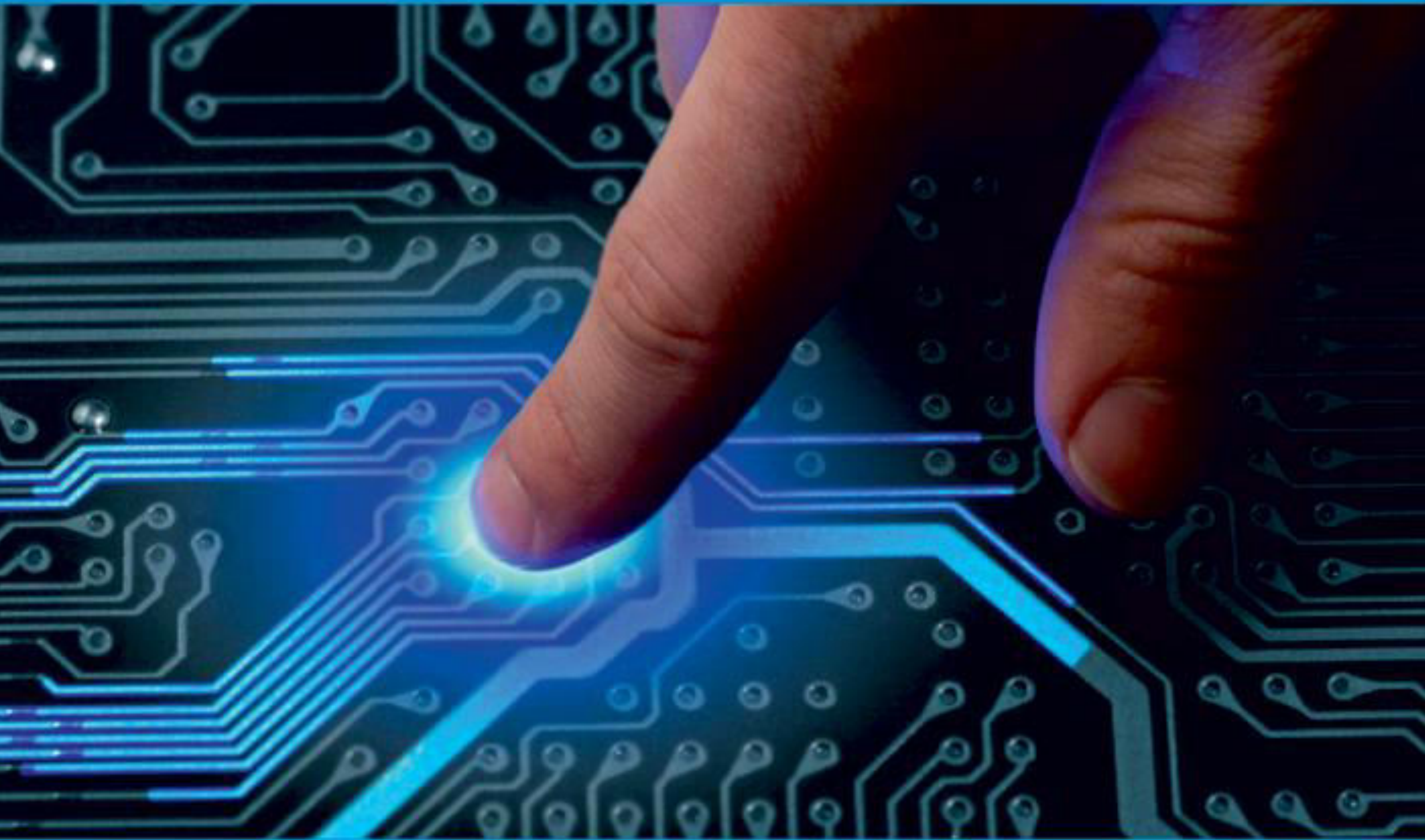

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A Robust - Firefly-Shearlet Transform Based Optimized Watermarking Scheme for Medical Images

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ABSTRACT: In contemporary e-healthcare systems, remote radiologists are frequently provided with medical images and patient data to aid in diagnosis. As a result, ensuring the accuracy of data transfer is of utmost importance. Digital communication has posed significant challenges, such as security, privacy, and authenticity concerns, in addition to its advantages. The findings indicate that the proposed watermarking technique produces less distortion compared to the latest methods. The proposed method for watermarking yields watermarked images with high NC, PSNR, and SSIM values, rendering them suitable for medical imaging purposes. When the scaling factor is set to 0.06, the scheme exhibits remarkable efficacy, as indicated by the extracted watermark's BER, NC, and SSIM values, which are either equivalent to or in near proximity to 1.

KEYWORDS: medical images, privacy, watermarking image, Shearlet Transform, Arnold Transform

I. INTRODUCTION

The technology of digital imaging is widely utilised in various diagnostic procedures, including MRI, CT, and ultrasound imaging, among other modalities. In medical practise, it is common to transmit diagnostic images and relevant medical data of a patient to a specialist physician who is located in a different geographical area. This is done to enable precise and accurate diagnoses [1]. The employment of telemedicine platforms has enabled radiologists to provide remote consultations to their patients, particularly in the context of the ongoing pandemic. Medical images are often transmitted through the internet, thereby facilitating accessibility during the patient diagnosis process. The integrity of visual content transmitted through communication channels is susceptible to unauthorised manipulation. Therefore, it is imperative to establish an authentication mechanism for the aforementioned images that can effectively verify their authenticity prior to diagnosis. Smart hospital applications ensure the privacy and confidentiality of patient data through the implementation of robust medical data security measures.

A watermarking solution that is deemed effective must possess the capacity to tackle noteworthy challenges and pressing demands. Typically, a prevalent approach utilised for watermarking entails the incorporation of a message, segments of strings, or an image that is intended to serve as a watermark into a pre-existing cover image. The efficacy of watermarking methodologies is contingent upon the ability of the watermarked image to obfuscate its origin. This suggests that watermarks should be undetectable by human senses. As per the findings of [2], an effective watermarking system must be formulated in such a way that it becomes infeasible to detect, eliminate, or alter the watermark. Diverse categories of inadequacies may emerge, encompassing aspects such as security, resilience, obscurity, capacity, and complexity [3]. This can be applied to a wide range of materials, including x-ray and CT scans, as well as verifying the brand of a sheet of paper [4]. According to [5] and [6], the taxonomy of watermarking technologies can be broadly divided into two categories, namely transform domain technologies and spatial domain technologies. The facile integration of a watermark in the spatial domain can be accomplished by altering the grey levels of specific pixels in the host image. Although watermarks can be incorporated in the spatial domain, such techniques frequently encounter issues with resilience and are vulnerable to focused attacks, as demonstrated by several research studies. The user has provided a list of seven citations, but has not provided any context or explanation for them. Further information is needed to understand the purpose and relevance of these citations [7] [8].

II. BACKGROUND AND RELATED WORK

This section offers a systematic examination of the scholarly works concerning digital watermarking methodologies for medical imagery. The present section and its subsection scrutinises diverse watermarking methodologies in the transform domain. A collection of highly cited research publications has been curated by us. The present overview initiates with an examination of the basic methodologies, practical implementations, and diverse forms

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of watermarking.

Digital watermarking is a highly sought-after subject of study within the multi-media signal processing field, garnering significant interest from both academic and commercial researchers. While there may be slight variations in the definition of watermarking in the literature, the definition presented by [10] appears to be the most prevalent. The process of incorporating metadata into data in a discreet manner is commonly known as watermarking. This portrayal highlights two essential characteristics of watermarking. Initially, the integration of data ought not to elicit any discernible effect on the principal visual representation. It is imperative that the communication is pertinent to the hosting platform employed for the image. The categorization of watermarking techniques can be attributed to their function as a means of concealing information. This classification pertains to scenarios in which the undisclosed data is not inherently connected to the principal medium. It is noteworthy that a number of authors utilise the term "watermarking" in a comprehensive sense to encompass the concealment of information.

Several scholarly articles pertaining to digital watermarking were published during the period spanning from the late 1980s to the early 1990s. The proliferation of publications in this field experienced a significant surge, largely due to the prevailing notion that watermarking could serve as a valuable tool in combating the proliferation of digital media piracy. At the outset, scholars primarily directed their attention towards a limited subset of host information, comprising of digital images, videos, and audio recordings. The scholarly literature has extensively recorded the development of watermarking methodologies that have been relevant to various types of media over the course of time. Digital representations comprise a diverse range of formats, such as voxel-based three-dimensional (3D) images, 3D models represented as polygonal meshes or parametric surfaces, vector graphics, gis data, animation parameters, object-based video representations, symbolic depictions of audio, and textual data [11].

2.1 Shearlet Transform

Shearlets are a framework that is capable of encoding anisotropic features in multivariate problem classes in an efficient manner, due to their multidirectional and multiscale nature. In [12], shearlets were initially proposed for the purpose of analysing and sparsely approximating functions. Shearlets are a mathematical tool that takes into account the presence of anisotropic characteristics, such as edges in images, which are commonly observed in multivariate functions. Nevertheless, wavelets are objects that exhibit isotropy and are insufficient in capturing such phenomena.

$$\begin{aligned} R &= F^L = \{(\xi_1,\xi_2), \epsilon\mathbb{R}^2 |\xi_1|, |\xi_2| \leq 1\}, \\ CH &= \{(\xi_1,\xi_2)\epsilon\mathbb{R}^2 | \frac{\xi_1}{\xi_2}| > 1, |\xi_1| > 1\} \\ CV &= \{(\xi_1,\xi_2)\epsilon\mathbb{R}^2 | \frac{\xi_1}{\xi_2}| > 1, |\xi_2| > 1\} \end{aligned} \tag{1}$$

2.2 Walsh Hadamard Transform

A square wave with maximum and lowest element values of 1 and -1 is the foundation for the wht, often known as the WHT. Because it simply has the elements 1 and -1, this transformation is a quick computation [13]. There are many signal and image processing fields that use the WHT, DCT, and DWT transform algorithms. These techniques compress the energy in the lower frequency components, resulting in a high-quality reconstruction. By analyzing and organizing the frequency components of the picture and the coefficients of its linear transformation. The kernels or bases used in image transformation not only provide edge information but also offer energy information. The energy information encapsulates the intrinsic attributes of a given image, including but not limited to its chromatic and textural properties that are specific to the local context. The wht confers a notable advantage owing to its superior ease of utilisation vis-Ã -vis alternative linear transform methodologies.. It is possible to define the WHT matrix as W_h with N sets of rows. The characteristics are (i) $W_h = 1 or - 1$, (ii) $W_h(0) = 0 \forall h = 1, \cdot, N-1$, (iii) W_h crosses all zeros. The WHTM has a size of 2 power (equation 2).

$$Wm(i,j) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f(u,v) * g(l,m,i,j) \tag{2}$$

where $Wm(i,j)$ are the results of the Walsh transform and g(l, m, e, f) are the kernels. $g(e,f,0,0)$ and $g(e,f,0,1)$ are the first and second kernels, respectively. The zero sequencing kernel is the first kernel.

2.3 Arnold Transform

The Arnold Transform is primarily utilised for the purpose of scrambling. Pixel scrambling is a technique employed in image processing to rearrange the spatial arrangement of pixels, with the aim of reducing storage requirements, as documented by the source [14]. The given object is a square matrix of dimensions N x N, with coordinates denoted by $K = (\alpha, \beta) | \alpha, \beta = 0,1,2, \ldots, N-1$. The algebraic term (AT) can be represented in the following manner:

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$$\begin{pmatrix}\alpha_n \\ \beta_n\end{pmatrix} = \begin{pmatrix}1 & \alpha \\ \beta & \alpha\beta + 1\end{pmatrix}\begin{pmatrix}\alpha_{n-1} \\ \beta_{n-1}\end{pmatrix} \text{modN} \quad (3)$$

The transformation of a and b after m iterations is performed with respect to $\alpha_{(n-1)}$ and $\beta_{(n-1)}$, using the coordinates α_n and β_n. It should be noted that a and b are positive values, while N represents the dimensions of a square matrix. Iterative AT is obtained when (α, β) undergoes multiple modifications. It returns to its previous state.

2.4 Firefly Algorithm

The inception of the Firefly Algorithm (FA) can be traced back to its development at the esteemed Cambridge University by Yang, in [15]. The current investigation presents a new optimisation methodology grounded on swarm intelligence, which takes cues from the flashing bio-luminescence exhibited by fireflies. The torch fulfils two primary functions, specifically attracting prospective mates and attracting potential prey. The Firefly Algorithm (FA) is based on the analogy that the brightness of fireflies is analogous to the optimisation problem's resolution. The level of brightness is directly related to the value of the objective function in a particular problem domain. Within the appropriate academic field, there exist three theoretical principles that are widely recognized as the FA.

$$r_{ij} = \|k_i - k_j\| = \sqrt{\sum_{k=1}^{c} \left(k_{i,k} - k_{j,k}\right)^2} \quad (4)$$

The spatial coordinate k_i of the i^{th} firefly is denoted by the variable $k_{i,k}$, where k denotes the index of the k^{th} element of the coordinate.

III. PROPOSED APPROACH

The incorporation of multimedia has had a significant impact on diverse domains of daily existence, including but not limited to commerce, academia, and healthcare. Multimedia images, including X-ray, mammography, CT-scan, and ultrasound pictures, are utilized in contemporary healthcare for the purpose of disease diagnosis [16]. The medical images are being transmitted through network channels. It is plausible that the image or its veracity may have been manipulated, whether deliberately or inadvertently. A secure and robust system is required to safeguard medical images against tampering.

This chapter introduces a digital watermarking technique for medical images based on the Shearlet Transform and Walsh Hadamard Transform. The Shearlets are a framework that is capable of encoding anisotropic features in multivariate problem classes in an efficient manner, due to their multidirectional and multiscale nature. Shearlets are a mathematical tool that takes into account the presence of anisotropic characteristics, such as edges in images, which are commonly observed in multivariate functions. Nevertheless, wavelets are objects that exhibit isotropy and are insufficient in capturing such phenomena. In contrast, it can be observed that in the realm of wavelet-based signal processing, the lower frequency components are subjected to a process of compaction, resulting in a reconstruction of superior quality. Through a meticulous analysis of the frequency components present in the image, coupled with the systematic classification of said components, and a thorough evaluation of the coefficients pertaining to the linear image transformation, one can gain a deeper understanding of the image in question. The fundamental constituents or rudimentary elements of the image metamorphosis, that furnish periphery particulars, may also furnish vigour particulars, which bestow regional features of an image such as texture and hue. The utilisation of the WHT is notably advantageous due to its comparative ease of use in contrast to other linear transformation methodologies.

3.1 Watermark Embedding Procedure

This section, the procedure for watermark embedding was expounded upon, as depicted in figure 0. Algorithm 3.1 outlines the sequential procedure for incorporating the watermark. During the initial stage of the watermark embedding process, a Shearlet transform is employed to the host image. The image designated as a watermark is incorporated within the lower frequency. In the second step, the coefficients are transformed into blocks of size 3×3. In the third step, the wht is applied to each blocks to get Wh_{matrix} matrices. These matrices are used to embed the watermark image. The watermark images are embedded into the central elements of the matrix. In fourth step of the process, Arnold Transform is employed on the watermark image and $W_{m'}$ is obtained. In the fifth step of the process, the watermark bits are incorporated into Wh_{matrix} matrix through an additive quantisation mechanism with the help of a scaling factor denoted as Δ. The quantification of the numerical magnitude of Δ is attained by means of the application of the Firefly algorithm. In the sixth step inverse Shearlet Transform is employed to get Watermarked image as H'_m. Finally, the watermark images is obtained in step seven.

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Algorithm 1 Watermark Embedding Procedure

Require: A host image (H_m) and the value of Δ.
Require: A watermark (W_m).
Ensure: Watermarked Image (H'_m)
1: coefficients = shearlet(H_m)
2: block = IntoBlocks(coefficients) of size 4×4
3: Wh_{matrix} = WHT(block)
4: W'_m = AT(W_m)
5: embed the coefficients of W'_m into the central element of Wh_{matrix} using Δ to get Wh'_{matrix}
6: (H'_m) = InverseShearlet(Wh'_{matrix})
7: Watermarked Image as (H'_m)

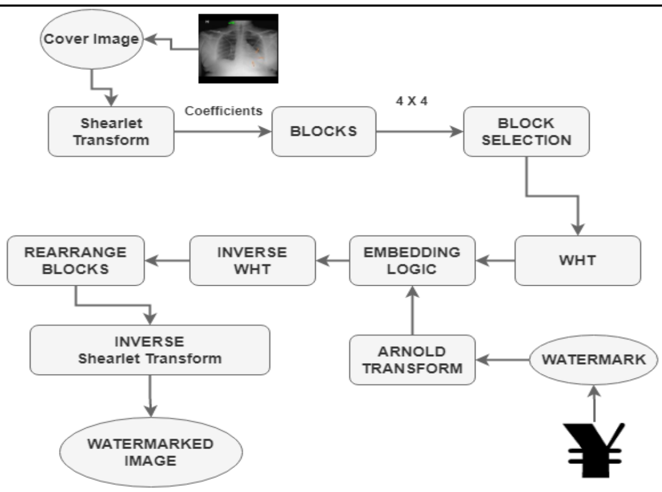

Figure 1: Block Diagram: Watermark Embedding Process

3.2 Watermark Extraction Procedure

The subsequent passage delineates the methodology employed for the extraction of watermarks. The process of extracting the watermark is illustrated in Figure 1. Algorithm 3.1 provides a comprehensive description of the methodology employed for the incorporation of the watermark. Algorithm 3.2 receives as input the image H'_m, and a Δ as msf, and produces as output a watermarked image W''_m. During the initial stage of the watermark extraction process, the watermarked image undergoes a transformation via Shearlet transform, which yields the coefficients of the lower frequency. During the second step, the coefficients pertaining to the lower frequency are subjected to a transformation process that results in the formation of blocks with dimensions of 4×4. In the third phase, the wht is carried out by each block, resulting in the production of Wh_{matrix} matrix. The fourth step entails employing the equation provided therein. Ultimately, during the fithe step of the process, the AT is employed on the extracted watermark bits of in order to obtain the extracted watermark

Algorithm 2 Watermark Extraction Algorithm

Require: Watermarked Image (H'_m) and Δ.
Ensure: Extracted Watermark (W'_m)
1: coefficients = shearlet(H'_m)
2: block = IntoBlocks(coefficients) of size 4×4
3: Wh_{matrix} = WHT(block)
4: $W'_m = \begin{cases} 1, & \text{if } W'_m + \Delta \leq \lambda \\ 0, & \text{Otherwise} \end{cases}$
5: W''_m = InverseAT(W'_m)
6: Extracted watermark as (W''_m)

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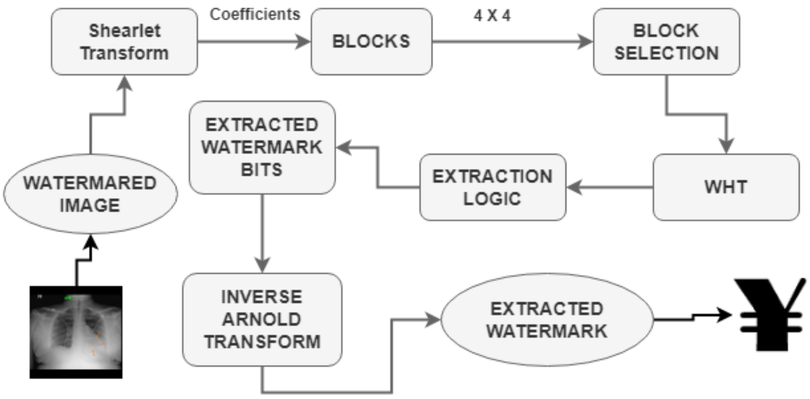

Figure 2: Block Diagram: Watermark Extraction Process

IV. RESULTS AND DISCUSSION

This section presents experimental results that demonstrate the efficacy of the proposed technique across various watermarking dimensions, including imperceptibility, resilience, security, and payload. The aforementioned discoveries can be located within the subsequent sections. The aforementioned results are being presented in this section of the report due to their prior presentation elsewhere. The aforementioned attributes can be deconstructed into their constituent elements, such as imperceptibility, resilience, security, and payload. The current experimentation involves the utilisation of a computer system equipped with an Intel Core i7-8600 central processing unit (CPU) operating at a frequency of 3.0 gigahertz. The system is also equipped with a 64-bit processor and 64 gigabytes of random access memory (RAM), and is running the Windows 11 operating system. The majority of the experimental procedures conducted by the group are facilitated through the utilisation of MATLAB R2018b as the preferred instrument.

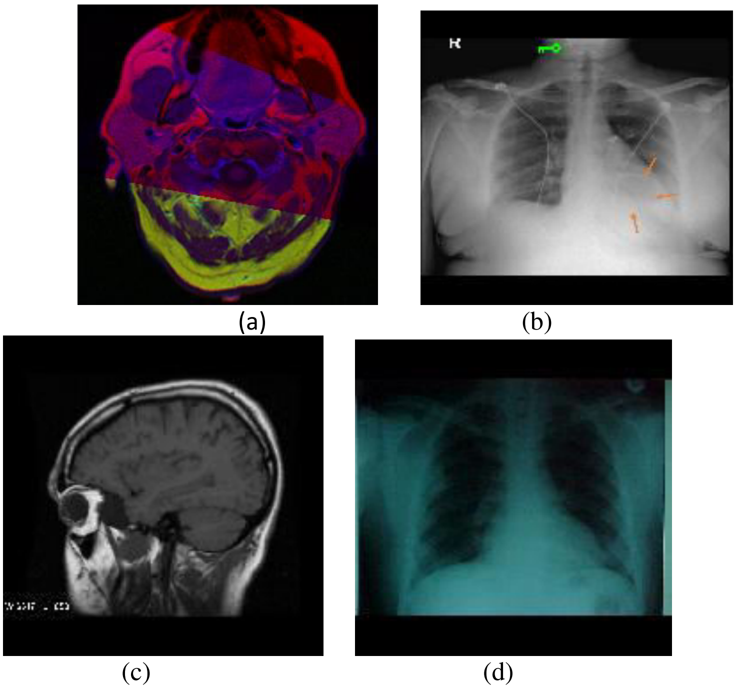

Figure 3 : Images employed for the purpose of experimentation.

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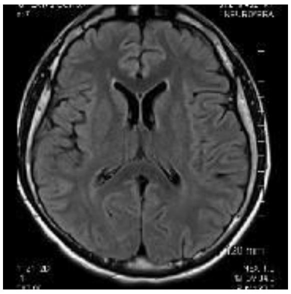
(e)



(f)

(g)

(h)

Figure 4 : Watermark Image

The extracted ber, psnr and ssim values of the watermarked images are presented in Table 0. The maximum achievable values for ber, psnr and ssim were identified as 0.9876, 47.7132 and 0.9792, correspondingly. The statement above underscores the considerable level of confidentiality that a watermark imparts to an image that has undergone the watermarking process, due to the watermark's nearly imperceptible character. Moreover, the methodology employed for the removal of the watermark has demonstrated efficacy in its execution. Eliminating watermarks from images leads to the emergence of NC values that lack any watermarks. The close proximity of the NC values to a value of one provides a reliable indication of the effective performance of the extraction methodology.

Table 1: Experimental Result

The Metrics of Evaluation	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Embedded Image	PSNR	55.1246	55.4519	55.2419	55.8745	55.1429	55.5615
	SSIM	1.5000	1.5000	1.5000	1.5000	1.5000	1.5000
	NC	0.9978	0.9892	0.9897	0.9791	0.9898	0.9993
Extracted Image	SSIM	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000
	NC	0.9985	0.9886	0.9888	0.9889	0.9968	0.9891

V. CONCLUSION

The rise of electronic healthcare, supported by the medical community, will help smart cities establish a healthy society. E-healthcare systems provide medical images and patient data to remote radiologists for diagnosis, therefore data transfer accuracy is crucial. Digital communication brings security, privacy, and copyright issues along with its benefits. Consequently, content owners, corporations, and technology protect their rights and content. An efficacious watermarking solution ought to possess the capability to address a multitude of substantial challenges and compelling necessities. A robust watermarking system can manage many difficult issues and demanding needs. Watermarking scheme embeds and extract text, string fragments, or images onto cover images. Watermarking schemes only work if the item they are applied to conceals the image's origin. A secure watermarking system should prevent detection, removal,

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and alteration. However, there are many challenges for the development of a watermarking scheme which include security, robustness, invisibility, capacity, and complexity.

Hence, the current investigation proposes a grayscale image watermarking methodology for medical images. The proposed methodology is founded upon the utilisation of the Contourlet and Slantlet transforms. The Arnold transform is utilised to obfuscate the watermark, thereby enhancing the security and resilience of the scheme. The proposed methodology employs the low frequency band of Contourlet transform, utilising the LL sub-band for watermark embedding. The outcomes of our experiment exhibit superior performance in comparison to alternative approaches with regards to visual fidelity and resilience against various forms of attacks. Furthermore, it is important to note that our study is restricted to monochromatic images exclusively.

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