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SECURE MR IMAGES WITH REVERSIBLE DIGITAL WATERMARKING FOR ENHANCED INTEGRITY AND AUTHENTICITY

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ABSTRACT—

Digital watermarking is a technique that involves embedding information within existing digital content to manage digital rights (DRM) and ensure authentication. Reversible watermarking, a specific type of fragile digital watermarking, not only verifies the authenticity of multimedia data but also preserves the perfect integrity of the original "cover data." Digital image watermarking is a widely used technique for securing image content, and an effective watermarking method must be accurate, reversible, resilient, and resistant to various forms of attack. The technological advancements brought about by digital technologies in medicine have led to new developments in many medical fields. Protecting the authenticity and integrity of medical images, such as Magnetic Resonance (MR) images, is crucial. This paper presents a reversible digital image watermarking technique designed to safeguard the integrity and authenticity of MR images. Reversible watermarking is considered a robust method for confirming the integrity and authenticity of medical images, ensuring that any alterations can be detected and traced back.

Keywords: Digital watermarking, Reversible watermarking, medical images and Magnetic Resonance images.

I. INTRODUCTION

With the widespread reach and popularity of the Internet, coupled with the rapid advancement of multimedia technology, protecting image copyrights has become a significant concern. Digital image copyright issues are receiving increasing attention, especially as information security techniques, including digital watermarking, have evolved to meet these challenges. Digital watermarking has recently emerged as a promising solution for protecting and securing digital images and their contents [1].

The technological revolution spurred by the development of digital technologies in medicine has introduced new approaches across various medical fields [2]. In many medical imaging domains, traditional diagnostic methods have transitioned to digital, or e-diagnosis, workflows. Hospital Information Systems (HIS) and medical imaging platforms handle digital images generated across multiple modalities, such as X-ray, Ultrasound, Magnetic Resonance (MR), and Computerized Tomography (CT). These images are stored in Picture Archiving and Communication Systems (PACS) and managed according to the Digital Imaging and Communications in Medicine (DICOM) standard.

The transfer of medical images across hospitals, locations, and organizations has become routine for various purposes, including diagnosis, treatment, training, remote learning, and consultations between clinicians and radiologists. While most transfers occur within PACS workflows, images and data are sometimes moved outside of these systems, either for legitimate reasons or, occasionally, for illicit purposes. During these exchanges, medical images can be unintentionally or intentionally tampered with, potentially leading to misdiagnoses [3]. Such tampering can have severe consequences, including life-threatening outcomes. Therefore, maintaining the integrity and authenticity of medical images, both within internal systems and during transfer, is crucial.

Digital image watermarking provides a method for ensuring tamper resistance, protecting intellectual property rights, and enhancing the security of multimedia documents. Digital watermarking allows data to be hidden in any digital content, such as images, audio, and videos, which can otherwise be illegally copied, duplicated, and distributed during transmission, processing, and storage.

Medical image watermarking techniques are categorized into three types: conventional methods, Region of Interest (ROI), Region of Non-Interest (RONI), and reversible approaches. Reversible watermarking techniques are designed to prevent permanent image distortion by enabling the exact recovery of the original image at the receiving end. Reversible watermarking embeds information into the carrier image while preserving visual quality, allowing for the lossless reconstruction of the host image after extracting the watermark. Unlike traditional watermarking methods, reversible techniques face greater demands for embedding information, making them valuable in fields such as judiciary, military, and medical applications where high image authenticity and integrity are required.

The primary goal of reversible image watermarking algorithms is to maximize the embedding capacity while minimizing distortion. In medical contexts, any alteration of an image during workflow processes can undermine trust in its validity, potentially leading to misdiagnosis or uncertainty with life-threatening or legal implications. Therefore, retrieving the original data from a modified image is essential. Reversible or lossless watermarking methods meet this requirement by guaranteeing the extraction of the watermark and the full recovery of the unaltered original image. This paper presents fully reversible watermarking techniques to ensure the privacy and integrity of MR images, allowing for the complete recovery of both the original unmodified image and the embedded watermark.

II. LITERATURE SURVEY

Xiang Hou, Lianquan Min, Hui Yang, and colleagues [5] present a reversible watermarking scheme for vector maps using multilevel histogram modification. This novel approach aims to enhance the security of vector maps while maintaining complete reversibility and good invisibility, as demonstrated by their experimental results. The method involves replacing pixel information with randomly placed salt-and-pepper noise in the image, which can later be extracted to remove the noise.

Irshad Ahmad Ansari, Millie Pant, and Chang Wook Ahn [9] introduce an artificial bee colony-optimized robust reversible image watermarking technique. Their study focuses on developing a lossless watermarking method that maximally fulfills the five basic requirements of an ideal lossless watermarking scheme: robustness, reversibility, invisibility, security, and capacity.

R. Lakshmi Priya and V. Sadasivam [10] propose a scheme for protecting health imagery through region-based lossless reversible watermarking. This approach combines hashing, compression, and digital signature techniques to create a content-dependent watermark using a compressed region of interest (ROI) for recovering the original ROI. Experimental results confirm that the ROI is extracted intact.

Llukman Çerkezi and Gökçen Çetinel [11] propose a secure digital image watermarking method based on Redundant Discrete Wavelet Transform (RDWT) and Singular Value Decomposition (SVD), using Arnold Cat Map (ACM). By leveraging the complexity of chaotic signals, the method enhances both robustness and invisibility.

Anu Bajaj [12] presents a robust and reversible digital image watermarking technique based on a hybrid method using RDWT, DCT (Discrete Cosine Transform), and SVD.

Mohammad Shahab Goli and Alireza Naghsh [6] introduce a new method resistant to crop attacks in digital image watermarking using a two-step Sudoku approach. This method scatters the watermark image across two Sudoku table layouts, repeating it 81 times in the host image, allowing for reconstruction even if parts are cropped by an attacker.

Zhengwei Zhang, Lifa Wu, Yunyang Yan, Shaozhang Xiao, and He Sun [7] propose an improved reversible image watermarking algorithm based on difference expansion, which aims to enhance visual quality and embedding rate. The algorithm divides the watermark information into groups and calculates the information value for each.

Khalil Shekaramiz and Alireza Naghsh [8] present a method for embedding and extracting two separate images within salt-and-pepper noise in digital images. This method utilizes various transforms like RDWT, DCT, SVD, and trigonometric functions. The effectiveness of the method is measured using a correlation-based extraction mechanism with a robustness tolerance level of 0.8.

Arijit Kumar Pal, Nilanjan Dey, Sourav Samanta, Achintya Das, and Sheli Sinha Chaudhuri [13] introduce a hybrid reversible watermarking technique for color biomedical images using an Odd-Even Method for watermark insertion and extraction. This method ensures high data hiding capacity, security, and high-quality watermarked images.

Neeraj Bhargava, M.M. Sharma, Abhimanyu Singh Garhwal, and Manish Mathuria [14] present a digital image authentication system based on digital watermarking using Discrete Wavelet Transform (DWT). The system consists of two functions: one for hiding information within the image and another for detecting it.

Koushik Pal, Goutam Ghosh, and Mahua Bhattacharya [15] propose a reversible digital image watermarking scheme using bit replacement and a majority algorithm technique. Their approach involves recovering data from damaged copies by applying a majority algorithm to identify the closest match to the embedded information.

III. REVERSIBLE DIGITAL IMAGE WATER MARKING TECHNIQUES

This paper presents a reversible digital image watermarking technique to ensure the integrity and authenticity of MR images. The block diagram of the proposed technique is illustrated in Figure 1. In a secure communication model, the digital image watermarking process consists of two main parts: watermark embedding and watermark extraction.

During the watermark embedding process, the cover image is initially pre-processed, and its entropy is calculated to determine the embedding capacity of the image. An optical image encoding method is then used to embed the watermark into the high entropy regions of the host image using a secret key. The system subsequently adjusts the amplitude and phase shaping information of a laser beam to generate the watermarked image.

In the watermark extraction process, the watermarked image undergoes pre-processing, after which the system extracts the amplitude and phase shaping information of the laser beam patterns. The entropy of these patterns is evaluated, and regions with high entropy values are selected to extract the watermark, ensuring enhanced integrity and authenticity.

Magnetic Resonance (MR) spectroscopy is a non-invasive diagnostic technique used to measure biochemical changes in the brain, particularly for detecting tumors. Magnetic Resonance Imaging (MRI) employs a strong magnetic field and radio waves to produce detailed images of internal organs and tissues. This approach utilizes brain MR images, segmenting them into two parts: the Region of Interest (ROI) and the Region of Non-Interest (RONI). The watermark data is encoded into the ROI using reversible watermarking.

In computer vision, the ROI represents the area of the image where an object of interest is located, allowing for targeted operations, while the RONI typically represents the background of the image.

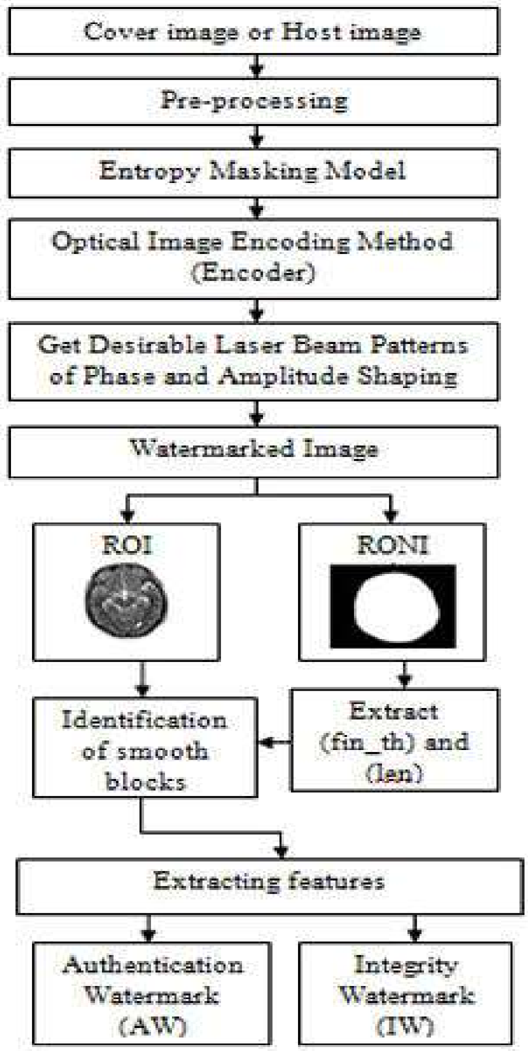

Fig. 1: Block Diagram Of Presented Reversible Digital Image Watermarking Technique

In addition to the raw image data, DICOM (Digital Imaging and Communications in Medicine) defines a structured format for describing medical images, known as metadata, which is stored in the image header. DICOM metadata consists of tables of attributes that record key information such as the time of image acquisition, device parameters, imaging conditions, diagnostic results, and critical patient details, including name, ID number, age, gender, weight, and height. Some metadata fields change each time the image is distributed, while others remain constant. To ensure the authenticity of the image, only the constant data related to the patient and image should be used.

The Digital Signature (DS) of the original medical image is calculated using the Message Digest (MD5) algorithm, a cryptographic hash function that generates a 128-bit Message Authentication Code (MAC). Any alteration to the image, whether intentional or accidental, results in a change in the hash code. By comparing the original and retrieved hash codes, image manipulation can be detected. In this study, the DS of the entire image is computed and embedded into the medical image to provide a strict integrity watermark (IW).

Most medical images contain large smooth areas regions with minimal variation between adjacent pixel intensity values. Embedding the watermark in these smooth regions makes it less perceptible to the human eye. Thus, the watermark is encoded within the smooth areas inside the Region of Interest (ROI) to minimize the degradation of the watermarked image. When using existing techniques to identify smooth regions, some blocks identified as smooth during extraction may not precisely match the original blocks used during embedding. This discrepancy can prevent the accurate extraction of the encoded data and hinder the recovery of the original image.

To address this, a new algorithm is introduced to accurately identify smooth regions within the ROI of a medical image. This algorithm ensures that the same smooth blocks are identified during both the embedding and extraction processes, enabling precise data extraction from the watermarked image without requiring additional information, such as a location map. The algorithm segments the ROI into non-overlapping blocks of 3 × 3 pixels, which are evaluated and classified as either smooth or non-smooth. The parameters len (the length of the watermark data) and fin_th (the final threshold used to identify smooth blocks) are extracted.

After the image is segmented into ROI and Region of Non-Interest (RONI) and the smooth blocks within the ROI are identified, the watermark data is encoded. The watermark is then extracted from the recalculated watermark of the extracted image to verify the image's authenticity and integrity.

The extracted watermark is decompressed using the Run-Length Encoding (RLE) method and divided into two parts: the authentication watermark (AW) and the integrity watermark (IW). These watermarks are compared with the recalculated metadata and the DS of the extracted DICOM image to confirm the image's authenticity and integrity. This is achieved by calculating the number of correct and incorrect bits between the extracted and recalculated watermarks.

IV. RESULT ANALYSIS

This section presents the result analysis of a reversible digital image watermarking technique designed to ensure the authenticity and integrity of MR images. The proposed method guarantees the authenticity and integrity of both the pixel data and the header information of the watermarked image. This is achieved only when the embedded watermark and the original image are accurately retrieved and perfectly match. Any manipulation of the image data leads to corruption of the embedded watermark, causing a mismatch between the original and the retrieved watermarks. The original image, the watermark image, and the extracted images are displayed in Figure 2.

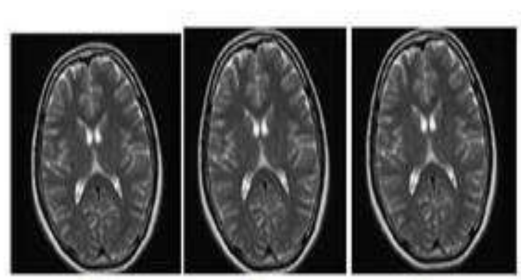

Fig. 2: (a) Original Image, (b) Watermarked Image and (c) Extracted Image

Figure 2 illustrates examples of the original MR images alongside their corresponding watermarked and extracted versions, as well as the differences between the original and extracted images. There is no visible difference between the original and watermarked images, and no numerical difference between the original and extracted images. The reversibility of the watermarking technique and its ability to recover the embedded watermark after both intentional and unintentional modifications are evaluated using the Peak Signal to Noise Ratio (PSNR) and Bit Error Rate (BER).

PSNR is a standard metric used to estimate the level of distortion between the original and watermarked images, with a higher PSNR value indicating lower distortion.

$$PSNR\ (I_o, I_w) = 10 \times\ log_{10} \frac{MAX_p}{MSE} \qquad (1)$$

Where MAXl represents the highest possible pixel value of the input images, and MSE is the Mean Squared Error between the original and watermarked images.

Bit Error Rate (BER): It is expressed as the ratio of the number of bit errors to the total number of bits transmitted, received, or processed. BER is used to measure the accuracy of the extracted watermark, with a lower BER indicating fewer errors and better recovery performance.

$$BER = \frac{Number\ of\ Error\ bit}{Total\ number\ of\ watermark\ bits} \qquad (2)$$

The presented technique demonstrates a significantly higher PSNR compared to other reversible watermarking methods, with BER values close to zero. This suggests that the embedded watermark can be recovered without any loss during extraction. When the image has minimal noise and no errors, its authenticity and integrity are greatly enhanced. The results confirming the authenticity and integrity of the proposed system are shown in Figure 3 below.

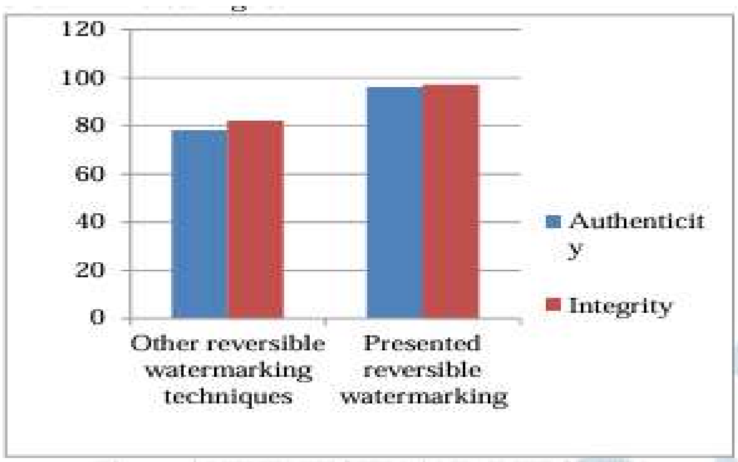

Fig. 3: Authenticity And Integrity Comparision Graph

Therefore, this reversible digital image watermarking technique demonstrates superior integrity and authenticity for MR images compared to earlier methods.

V. CONCLUSION

This paper presents a reversible digital image watermarking technique designed to ensure the integrity and authenticity of MR images. The approach segments the image into two parts: the Region of Interest (ROI) and the Region of Non-Interest (RONI). For a secure communication model, the watermarking process is divided into two phases: watermark embedding and watermark extraction. During the watermark embedding phase, the image data is preprocessed, and its entropy is evaluated. The watermark data is embedded into the smooth blocks selected from the ROI. The proposed scheme utilizes an optical image encoding technique that hides data within the difference values of pixel pairs, encoding the watermark into the smooth blocks inside the ROI. After extracting the embedded watermark, the exact original images are successfully retrieved. Experimental results demonstrate that this technique achieves superior performance in terms of distortion level, Peak Signal-to-Noise Ratio (PSNR), and Bit Error Rate (BER) compared to earlier methods. Therefore, this reversible digital image watermarking technique effectively enhances the integrity and authenticity of MR images.

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