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Hybrid Mode of Medical Image Watermarking To Enhance Robustness and Imperceptibility

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Abstract*: *In Modern healthcare systems, diagnostic information of patients is managed digitally. Watermarking strategies plays a significant role to ensure the security, authenticity and management of biomedical images and related patient information. This paper explores different invisible Digital watermarking methods both in spatial and transform / frequency domain and then Hybrid method by combining two techniques to justify better results for medical images. Here, host image considered is a medical image and patient's information is a watermark which is embedded into it. The embedded watermark is hidden in medical host image and its quality should not be degraded to avoid misdiagnosis by doctors. In this paper, LSB, SVD, DCT, DWT and Hybrid techniques (DWT+SVD) are implemented for embedding and extraction process of invisible medical image watermarking. The performance is evaluated based on PSNR as a measure of imperceptibility and CRC & SSIM as a check of robustness. The attacks introduced are cropping, rotating, and noise like Gaussian, Salt & Paper, Speckle and Poisson. Results reveal that DWT provides higher PSNR values but it is robust for few attacks only. On the other side, SVD provides consistent SSIM for all attacks, although PSNR values are less than that of DWT. Hence a hybrid technique is implemented by incorporating benefits of DWT and SVD both and achieved optimal values of PSNR as well as SSIM to provide better security to medical images by preserving the quality as well.

Keywords* : *Hybrid, Medical Image Watermarking, PSNR, SSIM.

I. INTRODUCTION

New healthcare system is based on managing diagnosis information of patient in a digital way. Copyright and authentication issues are raised while exchanging Digital Images and data over internet. To ensure the security, authenticity and management of medical image and data through volume and distribution, various data hiding methods are used like Digital watermarking, Cryptography, Steganography, Digital Signature, Firewall etc. Out of all these Digital Watermarking is more secure and easy method of data hiding [3], [29]. Digital watermarking is a technique for hiding data into original signal.

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This hidden data can be retrieved later by using retrieval algorithm. The original signal and hidden data could be text, image, audio or video. In this paper digital image watermarking techniques are compared for medical images. It involves mainly two processes – Embedding and Extraction. Embedding is performed at source end and watermarked image is produced by embedding watermark (patient information) into host image (Medical image). Extraction is performed at destination end where watermark is extracted from the watermarked mage. While transferring or storing medical images, there could be intentional or unintentional attacks.

On the basis of human perception i.e. embedded watermark is visible or invisible to human eyes, digital watermarking is classified as Visible and Invisible watermarking respectively [28], [29]. Another classification is based on the extraction process. While extracting watermark, if host and watermark images are required then it is Non-Blind type. If watermark image and secret key are required then it is Semi-Blind type and if only secret key is required then it is Blind type watermarking. As per the operating domain is considered, Digital watermarking can be further classified into two parts- Spatial and Frequency / Transform domain [26]-[29]. Spatial domain is mainly focused on modifying the pixel values. Watermark is in the forms of bits or converted into bits and it is added to the pixel values. LSB, Additive, Patchwork and Texture mapping coding are the examples of the Spatial domain Techniques. In Frequency domain, an image is transformed into the frequency domain and watermark is added there. DFT, FFT, DCT, DWT and DHT are the transforms which can be used for frequency domain watermarking. Taxonomy of Digital watermarking is shown in Fig. 1. Although watermarking techniques of spatial domain are having less computational cost and complexity but they are less efficient and less robust against different attacks as compared to the Transform / Frequency domain techniques.

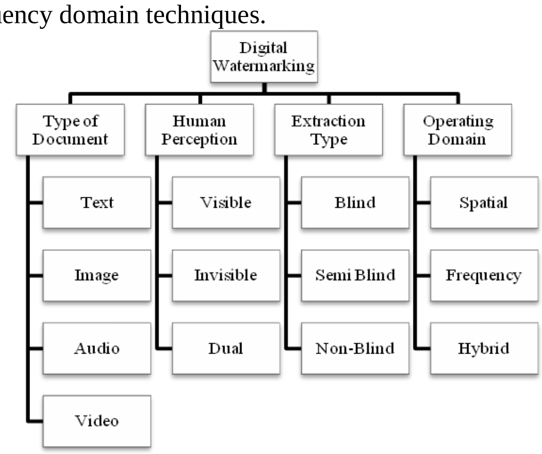


Fig. 1.Taxonomy of Digital Watermarking

The study reveals that researchers are mainly working in Frequency domain due to its advantages over spatial domain. Among various transforms of frequency domain, DWT and DHT are more robust.

Due to the verifiable features of DWT, wavelet based watermarking techniques picked up popularity. DWT based techniques are alluring a result of their simplicity and less computational weight. Further hybrid techniques are developed by researchers for integrating the advantages of both spatial and transform domain or different techniques of frequency domain itself [7], [8], [10], [17], [18], [25], [30]-[33].

Major constraints or characteristics required while performing Digital watermarking are – Imperceptibility, Robustness and Embedding Capacity [8], [26]. Imperceptibility is good when host image and the watermarked image are indistinguishable. MSE should be as low as possible and PSNR should be as high as possible. A robust digital watermarking algorithm should sustain against various intentional and unintentional attacks while storing or transmitting on unsecured network [27]. The watermark and host image should be extracted without degradation of quality of image. It is required for ownership / copyright protection. It can be evaluated by calculating CRC (Correlation Coefficient) and SIM (Similarity Measure) parameters. Embedding capacity is related to the size of watermark image in bits that is embedded into medical host image without major loss in robustness and imperceptibility. It is a key constraint in case of medical images as patient information is embedded as watermark, which is large information.

II. RELATED WORK

The literature survey or study of existing research paper is considering the main factor for the support of new enhancement and implements the technology. Lots of work for Digital watermarking have been carried out and are reported in literature. The work in the field of digital watermarking started with the spatial domain in 1993[1] and continued in the same domain [4], [8], [9]. Further researchers started working in frequency domain techniques [2], [8], [11] by identifying the advantages of frequency domain techniques over spatial domain in medical field. Later on it is also presented by few researchers that hybrid watermarking techniques are best which incorporates features of multiple digital watermarking techniques combining spatial and frequency / transform domain techniques [3], [5], [8], [31] or combining multiple frequency domain techniques [6], [7], [10]. Along with this, Multi-level watermarking [12] and multiple watermarks [6], [7], [11] are also used by few of them for medical images.

A technique for invisible watermarking for images using both non-blind (DWT) and blind embedding process (DWT & SVD) in outer cover image and inner cover image respectively is proposed by Savakar *et al.* [34]. PSNR and SSIM are achieved to optimal values but embedding capacity could be the constraint. Similarly Harsh Vikram Singh and Ankur Rai have implemented a hybrid model for medical image watermarking by applying combination of SVD and DWT on RONI [36]. The work is evaluated using PSNR & SSIM measures. The size of watermark image (logo) is varied and found that as the size of watermark increases, PSNR decreases. In other words, as the embedding capacity is increased, the quality of medical image decreases. K. J. Kavitha *et al.* implemented Digital Watermarking for medical images by combining Transform domain technique (DWT) and spatial domain technique (SVD) to prove the security [3]. Cryptography technique used is Symmetrical key generation. PSNR, MSE and SSIM are achieved to the optimal values, still more efficiency may be obtained by testing it against different attacks and data payload needs to be reduced.

A hybrid watermarking algorithm for color images using hybrid DCT and DWT is implemented and published by Abdulrahman *et al.* [35], where Arnold Transform is used to scramble the watermark image before applying DCT and DWT. Robustness is demonstrated by applying jpeg compression, resizing, rotating, filtering and noise. The method has better transparency with PSNR > 35dB for scaling factor 40. A homomorphic encryption technique using Number Theoretic Transform (NTT) in combination with key exchange protocol Diffie Hellman for security of medical images in cloud is presented by Soualmi *et al.* [2]. Execution time is fast 1.2 – 2.8 sec and new transform is tried but robustness is not tested against any attack.

Some work by integrating watermarking and cryptography also exists. Atta-ur-Rahman *et al.* applied reversible and fragile watermarking technique for medical in spatial domain using double chaotic key, RNS (Residual Number system) and CRC (Cyclic redundancy check) code [4]. After introducing the noise attacks, the original image is not recovered even though the initial conditions were applied. Robustness characteristics and capacity analysis are not included. Abdallah Soulmi *et al.* integrated multiple techniques by combining DCT, Weber Descriptors (WDs) and Arnold Chaotic map [5]. Watermark data is embedded in middle-band coefficients of DCT of ROI of medical image. The algorithm is tested for many attacks including noising, JPEG compression, filtering, and various geometric attacks. The robustness is improved against several attacks except translation, remove line, rescale and random distortions. Although the results are good but the major drawback is low embedding capacity. In the proposed algorithm, it is necessary to have at least 4N x 4N size cover image for NxN size binary watermark because a watermark bit is embedded in a 4x4 block size.

For medical images, region of Interest is also very important. Swaraja K presented a region-based, hybrid, firefly algorithm by combining DWT & Schur Transform along with multiple watermarking (Patient information and hospital logo) [6]. The cover medical image is separated in ROI and RONI and both the watermarks are embedded in RONI. The method is robust, imperceptible and attained reasonable embedding capacity. However, the results obtained are very encouraging. Author preserved ROI by embedding watermark in RONI but the ROI is not secured.

Another region based-watermarking algorithm by integrating cryptography is presented by Alavi Kunhu *et al.* [7].

Watermark is embedded in both the domains – Frequency domain using DWT & DCT and spatial domain. Along with this SHA256-MD5 Hash function is used for protection and authentication of Medical Images. Watermark information is added in RONI to preserve the radiological features present in ROI.

Although this method is sensitive to any modification or tempering and robust to few attacks, but need to check robustness for more spatial and frequency domain attacks. Also the embedding capacity analysis not presented in the paper. Patient's mobile number is only used as patient information and embedded in selected DCT coefficients. It shows the low embedding capacity.

Table I summarize the work done by researchers recently reported in literature for digital watermarking. It can be observed that most of the work is wavelet based. The review reveals that embedding capacity is the key gap for medical image watermarking. Secondly, region-based watermarking by integrating cryptography for preserving and securing ROI should be incorporated. While working with these, there should not be any compromise for imperceptibility and robustness.

Table- I: Summary of related work

Authors & Year	Methods & type	Encry--ption	Watermark embedded in	Remarks
Dayanand G. Savakar *et al.* [34] 2019	DWT+SVD Blind & Non-blind both	No	Whole Image	Optimum value of PSNR, SSIM. Embedding capacity is the constraint.
Abdulrahman *et al.* [35] 2019	DCT+DWT	No	Whole Image	Better transparency with PSNR > 35dB for scaling factor 40.
H V Singh and A Rai [36] 2019	SVD+DWT Blind	No	RONI	ROI is preserved but Embedding capacity is the constraint.
A. Soualmi *et al.* [2] 2018	NTT, Semi-blind	Yes	Each 16x16 block of whole image	Less computational complexity
K J Kavitha *et al.* [3] 2018	DWT+ SVD, Semi-blind	Yes	Whole Image	Optimum value of PSNR, SSIM. Embedding capacity is less
Atta-ur-Rahman *et al.* [4] 2018	RNS, Blind	Yes	Some of the pixels of image	Data payload is the limitation.
Abdallah Soualami *et al.* [5] 2018	DCT+ WDs	No	ROI	ROI needs to preserve. Low embedding capacity.
Swaraja K [6] 2018	DWT +Schur, Blind	No	RONI	ROI is preserved but not secured.
Alavi Kunhu *et al.* [7] 2017	DWT+DCT, Blind	Yes	RONI	Sensitive to tempering. Low embedding capacity.
Shubhangi *et al.* [8] 2017	DWT & SVD separately, Semi-blind	No	Whole image	Hybrid algorithm of DWT & SVD is concluded.
Musab Ghadi *et al.* [9] 2017	Jacobian Matrix, Semi-blind	No	Whole image	Embedding capacity is less. ROI needs to preserve and secure.

III. SPATIAL DOMAIN TECHNIQUES

In spatial domain techniques of digital watermarking, watermark bits are embedded to pixels of host image. Although these techniques are easy and simple to implement but cannot sustain against frequency domain attacks like filtering, noise etc.

A. LSB Method

It is a most common technique for spatial domain watermarking. It is basically based on human perception. As human eyes cannot distinguish small variation in color, small alterations in the LSB will not be noticeable. LSB contains very less information. LSB of each pixel in host image is replaced by the watermark bits and extracted in the same manner it is embedded.

Medical Image watermarking using LSB

In case of medical image watermarking, any medical image like MRI, CT-scan or X-ray images are host image and logo of hospitals or patient information can be taken as watermark image. The steps to perform LSB watermarking technique to medical image are:

Step 1: Read Medical host image
Step 2: Convert RGB image to gray scale image and resize to 256 x 256.
Step 3: Read watermark image Step 4: Convert it into binary
Step 5: Make double precision for images
Step 6: Remove LSBs from host image.
Step 7: Add watermark bits at the LSBs of host image to get watermarked image.
Step 8: Introduce attacks.
Step 9: For extraction, LSBs of watermarked image is separated and stored in the same sequence they were added.
Step 10: Calculate MSE, PSNR, CRC and SSIM measures.

Pros and Cons of LSB: Although it is easy and simple to implement and give good results without any attack, but it is not robust to various attacks like cropping, shuffling, scaling, noise, filtering etc.

B. SVD (Single Value Decomposition) Method

SVD is a method of linear algebra which transforms any matrix into product of three matrices (U, S and V^T). This factorization provides scope of SVD method to be used in image processing like image compression, face recognition, Image watermarking, Multi-scale signal analysis etc. In other words, it is an algebraic transformation of an image and its properties can be used for various image processing applications.

SVD factorizes an image I of size m x n with rank r such that $r \leq n \leq m$, into three components U, S and V:

$$I = U * S * V^T \tag{1}$$

Where U is an m x n orthogonal matrix

$$U = [u_1, u_2, \ldots \ldots . u_r, u_{r+1}, \ldots \ldots u_m] \tag{2}$$

$\mathbf{u}_i$ is a column vector for i =1, 2, ..., m and forms an orthogonal set:

$$u_i^T u_j = \delta_{ij} = \begin{cases} 1, i = j \\ 0, i \neq j \end{cases} \tag{3}$$

S is a diagonal matrix of size *m* x *n* with singular values (σ) on the diagonal.

$$S = \begin{bmatrix} \sigma_1 & 0 & \dots & 0 & 0 & \dots & 0 \\ 0 & \sigma_2 & \dots & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_r & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 & \sigma_{r+1} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 0 & 0 & \dots & \sigma_n \\ 0 & 0 & \dots & 0 & 0 & \dots & 0 \end{bmatrix} \qquad (4)$$

σ_i are Singular values (SV) of matrix *I* for $i = 1, 2, \dots, n$ with$\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_r > 0 \wedge \sigma_{r+1} = \sigma_{r+2} = \cdots = \sigma_N = 0$.

And *V* is an orthogonal matrix of size *n* x *n*

$$V = [v_1, v_2, \dots \dots .. v_r, v_{r+1}, \dots \dots \dots .. v_n] \qquad (5)$$

$\mathbf{v}_i$ is a column vector, for *i*=1, 2, ….., *n* and forms an orthogonal set:

$$\boldsymbol{v}_i^T \boldsymbol{v}_j = \delta_{ij} = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \qquad (6)$$

The column vector $\mathbf{v}_i$ of *V*, column vector $\mathbf{u}_i$ of *U* and diagonal vector $\boldsymbol{\sigma}_i$ of *S* are known as right singular vector, left singular vector and singular values respectively. The singular vector pair indicates the geometry of image while each singular value indicates the luminance of image [37].

Pros and Cons of SVD: In SVD method, watermark is embedded to Singular values which does not have an effect on the image quality and provides good imperceptibility and robustness.

Medical Image watermarking using SVD

The steps to embed watermark in medical images using SVD technique are:

Step1: Read Medical host image and watermark image.
Step 2: Convert them from RGB image to gray scale image and resize to 256 x 256.
Step 3: Apply SVD to host image to get U, S and V components.
Step 4: Select S part of decomposed image to embed watermark with scaling factor 0.0001.
Step 5: Combine this modified S part and original U and V parts to get watermarked image.
Step 6: Introduce Attacks.
Step 7: For extraction, apply SVD to watermarked image and separate it into U, S and V.
Step 8: Extract watermark from the S part.
Step 9: Calculate MSE, PSNR, CRC and SSIM measures.

IV. FREQUENCY DOMAIN TECHNIQUES

Watermarking in transform / frequency domain is based on alteration of coefficients in frequency domain. There are several transform domain methods which are commonly used watermarking, such as DCT, DWT etc.

A. Discrete Cosine Transform (DCT)

Digital Watermarking using DCT alters the frequency coefficients. It is a block based technique. DCT decomposes image in various frequency bands – Low frequency band (LF), Middle frequency band (MF) and High frequency band (HF) as shown in Fig. 2. Low frequency band carries most of the information while High frequency band carries least information. For embedding watermark information, high and middle frequency bands are preferred [29].

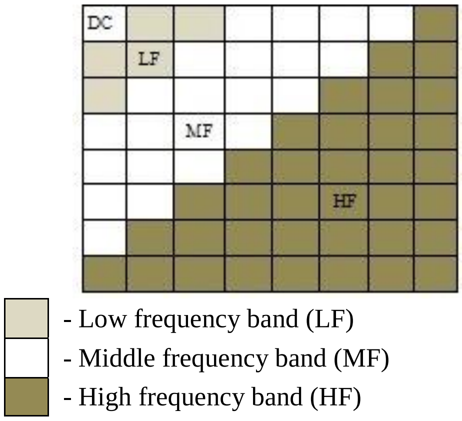


Fig. 2.Frequency bands of DCT coefficients

DCT of a 2D image is given by (7), where g(x, y) is *m* x *n* input image in spatial domain and G(u,v) are DCT coefficients. The block size is defined as *m* x *n*.

$$G(u,v) = \frac{2}{\sqrt{mn}} \propto (u) \propto (v) \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} g(x,y) \times cos\frac{(2x+1)u\pi}{2m} \times cos\frac{(2y+1)v\pi}{2n} \qquad (7)$$

Inverse DCT is given by (8),

$$g(x,y) = \frac{2}{\sqrt{mn}} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} \propto (u) \propto (v) G(u,v) \times cos\frac{(2x+1)u\pi}{2m} \times cos\frac{(2y+1)v\pi}{2n} \qquad (8)$$

where α’s coefficients are given by (9),

$$\propto (u) \propto (v) = \begin{cases} 1/\sqrt{2}, if u, v = 0 \\ 1, \quad otherwise \end{cases} \qquad (9)$$

Pros and Cons of DCT: DCT based watermarking is robust against filtering, noise etc. but cannot sustain some geometrical attacks like scaling, rotation etc. Computational complexity using DCT is very high.

Medical Image watermarking using DCT

The steps to perform digital watermarking on medical images using DCT are:
Step1: Read medical host image and watermark image.
Step2: Convert them to gray scale and double.
Step3: Resize them to 256 x 256.
Step4: Apply 2D DCT to host image.
Step5: Embed watermark bits to 2D DCT coefficients of host image using scaling factor 0.0001.
Step6: Apply 2D IDCT to get watermarked image.
Step7: Introduce attacks.

Step8: To extract the watermark, apply 2D DCT to watermarked image.
Step9: Subtract DCT coefficients of host image from that of watermarked medical image with factor 1/0.0001 to extract watermark.
Step10: Calculate MSE, PSNR, CRC and SSIM measures.

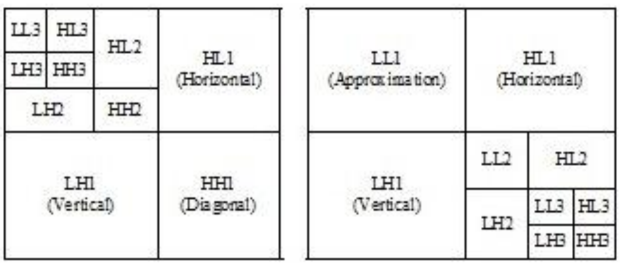
B. Discrete Wavelet Transform (DWT)

Most of the work is carried out by researchers with wavelet based watermarking techniques as it is computationally efficient and give good results for robustness against attacks. It is very powerful mathematical tool in many other fields also.

An image has smooth variations with fine details in between. These fine details are characterized by sharp edges. Smooth variations in an image are called as low frequency variation and sharp variation are called as high frequency variation. Hence low frequency part contains more energy and is more in demand than high frequency components. A 2D DWT separates the smooth variations i.e. low frequency components and sharp edge details i.e. high frequency components in LL sub-band (Approximation) and LH(Vertical), HL(Horizontal), HH(Diagonal) sub-bands respectively. This process can be repeated on any of these sub-bands up to k^{th} level as per the requirement of result. Fig. 3 (a) and (b) shows the 3-level DWT decomposition of an image in LL and HH sub-bands respectively.

For image watermarking, selection of sub-band for embedding watermark depends on the applications and type of images used. In literature, some researchers have used HL sub-band [11], [29], [34], few have embedded watermark in HH sub-band [10], [36] and others have used LL sub-band [7], [14], [30]. Also more than two sub-bands are used to embed different components or multiple watermarks [3], [6], [35].

After decomposing a brain MR Image using DWT and analyzing the energy of four sub-bands in the level 1, it is observed that energy is very high in LL sub-band. Energy in LH and HL bands are very less while that in HH band is negligible. The decomposition of brain MR image is shown in Fig. 4 and energy distribution is expressed in Table II. After applying DWT for embedding watermark in medical image, LL sub-band is providing better results.



(a) (b)

Fig. 3.A 3-level DWT decomposition of image in (a) LL sub-band (b) HH sub-band

Table II: Energy distribution of Brain MR Image after 2D DWT

Sub-bands	LL	LH	HL	HH
Energy	99.64 %	0.16 %	0.19 %	0.01 %
Entropy	59.2 %	16.5 %	16.1 %	8.3 %

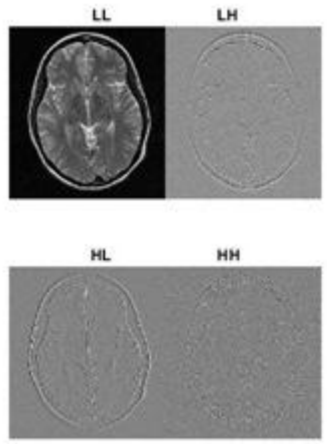


Fig. 4. Level 1 2D DWT decomposition of Medical image

Pros and cons of DWT: It provides better imperceptibility as compared to other techniques and good robustness to some frequency domain attacks and also effective in structural attacks. But computing cost and time is more.

Medical Image watermarking using DWT

The steps to perform digital watermarking on medical images using DWT are:
Step1: Read medical host image and watermark image.
Step2: Convert them to gray scale and double.
Step3: Resize host image to 256 x 256 and watermark image to 128 x 128.
Step4: Apply 2D DWT to host image.
Step5: Add watermark to LL band of host image using scaling factor 0.0001.
Step6: Apply 2D IDWT to get watermarked image.
Step7: Introduce any attack like noise, rotate, cropping etc.
Step8: For extraction, first apply 2D DWT to watermarked image.
Step9: Subtract LL sub-band of host medical image from that of watermarked image with factor 1/0.0001 to get watermark back.
Step10: Calculate MSE, PSNR, CRC and SSIM measures.

C. Hybrid Method

The various techniques of spatial domain and Transform domain are not giving good results for both imperceptibility and robustness. Some are providing better imperceptibility but not robust to various attacks. On the other hand, other techniques are robust to some attacks but imperceptibility is poor. To incorporate the advantages of multiple techniques, hybrid method is very useful.

Medical Image watermarking using Hybrid method (DWT +SVD):

By exploring the benefits of wavelet domain and SVD, hybridization is proposed. Steps to perform digital watermarking on medical images using hybrid (DWT+SVD) method are:
Step1: Read medical host image and watermark image.
Step 2: Convert them to gray scale and double.
Step 3: Resize host image to 256 x 256 and watermark image to 128 x 128.

Step 4: Apply 2D DWT to host image and decompose to LL, LH, HL and HH sub-bands.
Step 5: Apply SVD to LL sub-band to get U, S and V components.
Step 6: Select S part to embed watermark with scaling factor 0.0001.
Step 7: Combine this modified S part and original U and V parts to obtain modified LL sub-band back.
Step 8: Apply 2D IDWT with modified LL sub-band to obtain watermarked image.
Step 9: Introduce any attack like noise, rotate, cropping etc.
Step10: For extraction process, first apply 2D DWT to watermarked medical image.
Step 11: Apply SVD to LL sub-band and decompose it into U, S and V.
Step 12: Extract watermark from the S part.
Step 13: Calculate MSE, PSNR, CRC and SSIM measures.

V. PERFORMANCE PARAMETERS

While working with medical image watermarking, the quality of medical image and patient information needs to be preserved after embedding and extraction process. It is required to evaluate watermarked image on two measures – firstly quality of the watermarked image and secondly exactness of extracted watermark.

A. *Imperceptibility check for watermarked image*

By embedding patient information watermark in medical host image, some distortion will occur in watermarked image. As patient information is large size watermark, distortion will be more. Parameters used to measure the imperceptibility are MSE and PSNR [29].

- *MSE (Mean Square Error):* It is measured between Medical host image and watermarked image. The value of MSE should be as low as possible to achieve high imperceptibility. It is calculated by (10),

$$MSE = \frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j-0}^{M-1}\left(I(i,j) - I_w(i,j)\right)^2 \qquad (10)$$

where $I(i,j)$ represents medical host image and $I_w(i,j)$ represents watermarked image. Image dimensions are N x M.

- *PSNR (Peak Signal to Noise Ratio):* It is also measured between Medical host image and watermarked image. It is calculated by (11),

$$PSNR(I, I_w) = 10 \times log_{10}\frac{(MAX_I)^2}{MSE} \qquad (11)$$

where MAX_I is the maximum pixel value in host image. Larger the value of PSNR, more the similarity between the host medical image and the watermarked medical image. PSNR value should be ≥ 30dB [29].

B. *Robustness check of Extracted Watermark*

To check or evaluate the robustness against various attacks, following measures can be calculated between original watermark *w(i,j)* and extracted watermark *w'(i,j)* [29]:

- *CRC (Correlation coefficient):* It is used to calculate the compatibility between original watermark and extracted watermark. The maximum and minimum value of CRC is 1 & 0 respectively. It is calculated by (12),

$$CRC = \frac{\sum_i\sum_j W(i,j)W'(i,j)}{\sqrt{\sum_i\sum_j W(i,j)^2 * \sum_i\sum_j W'(i,j)^2}} \qquad (12)$$

- *SSIM (Structural Similarity Index):* It is used to calculate the image quality or in other words, structural similarities between original watermark and extracted watermark image. It is based on three key parameters of an image namely contrast (*c*), luminance (*l*) and structural (*s*). The multiplicative combination of these three terms results in value of SSIM. It is given by (13),

$$SSIM = [l(w,w')]^{\alpha}[c(w,w')]^{\beta}[s(w,w')]^{\gamma} \qquad (13)$$

where

$$l(w,w') = \frac{2\mu_w\mu_{w'}+C_1}{\mu_w^2+\mu_{w'}^2+C_1} \qquad (14)$$

$$c(w,w') = \frac{2\sigma_w\sigma_{w'}+C_2}{\sigma_w^2+\sigma_{w'}^2+C_2} \qquad (15)$$

$$s(w,w') = \frac{\sigma_{ww'}+C_3}{\sigma_w\sigma_{w'}+C_3} \qquad (16)$$

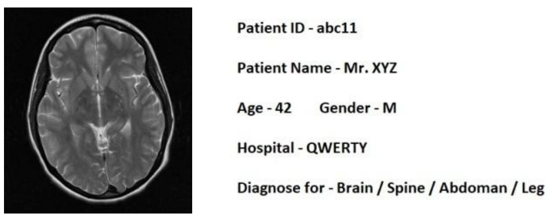
where σ_w, $\sigma_{w'}$, μ_w, $\mu_{w'}$ and $\sigma_{ww'}$ are standard deviations, local means and cross-covariance of *w* and *w'* images respectively. For $C_3 = C_2/2$ and $\alpha = \beta = \gamma = 1$, the SSIM is simplified to (17):

$$SSIM = \frac{(2\mu_w\mu_{w'}+C_1)(2\sigma_{ww'}+C_2)}{(\mu_w^2+\mu_{w'}^2+C_1)(\sigma_w^2+\sigma_{w'}^2+C_2)} \qquad (17)$$

VI. RESULTS AND DISCUSSION

The basic digital watermarking techniques are implemented in MATLAB R2018b on medical images. MRI of brain is considered as host medical image and patient information is considered as watermark image. Original medical host image and patient information as watermark image are shown in Fig. 5. The size of image is considered as 256 x 256.

A comparative analysis is presented by showing extracted watermark images with various techniques of digital watermarking after applying attackes like noise, rotating, cropping in Fig. 6. Noises introduced here are Gaussian, Salt & Pepper with 0.001, Speckle with 0.0001 and Poisson. Rotating is applied of 5^o and Cropping is done 30 % approximately in all the cases.



(a) (b)

Fig. 5. (a) Brain MRI as host image (b) Patient information as watermark image

It can be observed from the Fig. 6 that LSB can sustain only salt and pepper noise.

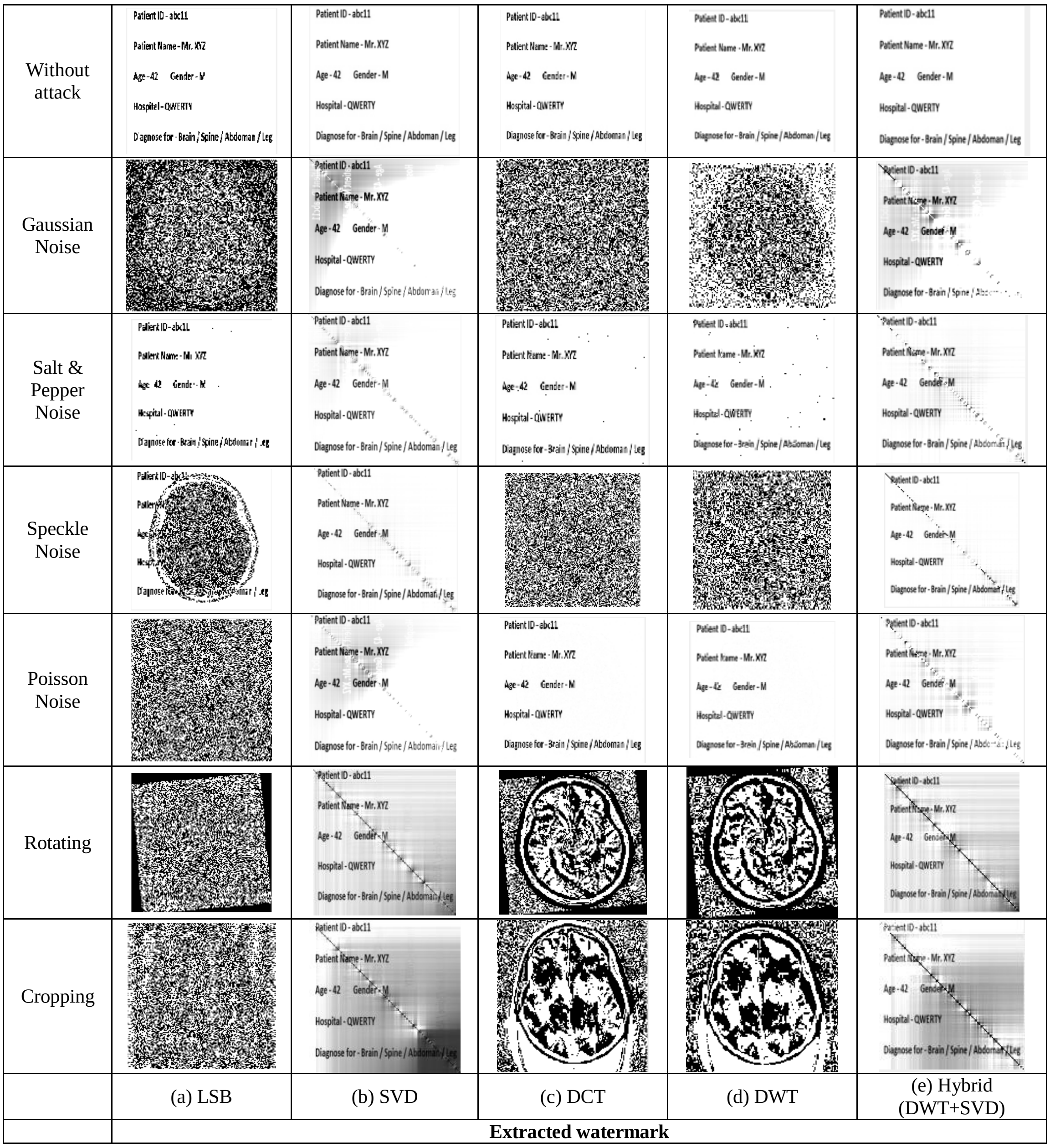


Fig. 6.Extracted watermark with various watermarking techniques after applying attacks

Frequency domain techniques DCT & DWT can sustain Salt & pepper and Poisson noise but these three techniques are having very poor sustainability against Gaussian noise and geometric attacks i.e. rotating and cropping. On the other hand, SVD performs well to some extent for all the attacks mentioned. Extracted watermarks are showing slightly poor results for Gaussian, rotating and cropping attacks. Further by combining DWT and SVD, these results are improved and hybrid technique provides better results for all attacks.

Quantitative comparative analysis is based on performance parameters PSNR, CRC and SSIM measures. To evaluate imperceptibility, PSNR is calculated between original medical host image and watermarked medical image. To evaluate robustness, CRC and SSIM measures are calculated between original patient information watermark and the extracted one. The results are expressed in table III and IV using watermarking techniques LSB, DCT, DWT and Hybrid (DWT+SVD) with various attacks. The results shows that as the imperceptibility is concerned, LSB, SVD, DCT & DWT techniques are providing good results as the PSNR values are ≥ 30 dB for all the attacks. Out of these, frequency domain techniques (DCT & DWT) are showing better imperceptibility as compared to others but while talking about the robustness; these techniques are robust to few attacks only. On the other side SVD provides consistent robustness for all the attacks. By combining, DWT and SVD, both PSNR and SSIM are achieved to some optimal values.

Table III: Quantitative Comparative Analysis of watermarking techniques for Imperceptibility check

Attacks	Performance Parameter PSNR (dB) between original host image and Watermarked Image				
	LSB	SVD	DCT	DWT	Hybrid (DWT+SVD)
Without attack	63.6711	103.5961	128.4109	134.4800	107.4510
Gaussian Noise	30.5964	29.8600	69.1847	69.2442	29.8552
Salt & Pepper Noise	55.4444	57.7378	83.0292	81.6417	57.5960
Speckle Noise	55.1269	52.9716	98.8909	98.9520	52.9419
Poisson Noise	35.1500	34.1572	115.1364	115.2924	34.1829
Rotating	30.0585	29.3229	62.6490	62.6487	13.8475
Cropping	31.2590	30.2519	62.2476	62.3505	13.0833

Table IV: Quantitative Comparative Analysis of watermarking techniques for Robustness check

Attacks	Performance Parameter CRC & SSIM between original watermark and extracted watermark									
	LSB		SVD		DCT		DWT		Hybrid (DWT+SVD)	
	CRC	SSIM	CRC	SSIM	CRC	SSIM	CRC	SSIM	CRC	SSIM
Without attack	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Gaussian Noise	0.6208	0.0023	0.0579	0.1210	0.1521	0.0000	0.2762	0.0000	0.0702	0.2320
Salt & Pepper Noise	0.9998	0.9817	0.0642	0.2047	0.0180	0.7936	0.0448	0.4973	0.0961	0.2956
Speckle Noise	0.8380	0.4052	0.4296	0.2620	0.0450	0.0013	0.0470	0.0009	0.3342	0.3555
Poisson Noise	0.6848	0.0048	0.0650	0.1863	0.2635	0.8854	0.2588	0.7788	0.0924	0.2842
Rotating	0.6516	0.0031	-0.0166	0.1979	-0.1648	0.0000	-0.1758	0.0000	-0.0315	0.2534
Cropping	0.7142	0.0050	-0.0100	0.1698	0.1991	0.0000	0.1921	0.0000	-0.0047	0.2391

VII. CONCLUSION

Performance results of LSB, SVD, DCT, DWT and Hybrid (DWT+SVD) techniques of Digital Image watermarking specifically for medical images are presented in figure 5 and table 2, 3. It can be seen from the results that maximum PSNR is obtained in case of DWT technique as compared to others. On the other side, SVD has consistent SSIM for all the attacks. In this paper, PSNR is a measure of imperceptibility and SSIM is measure of robustness. Therefore a hybrid technique by combining DWT and SVD is implemented for medical image watermarking to incorporate benefits of both the techniques and better and consistent results are obtained than individual. This relative analysis further suggested to develop any other hybrid algorithm of either two or more frequency domain techniques or of spatial and frequency domain techniques to achieve more optimal results for not only imperceptibility and robustness but also for high embedding capacity for Medical Image Watermarking.

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