Journal of Theoretical and Applied Information Technology
15th January 2022. Vol.100. No 1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

THE TRADE-OFF BETWEEN ROBUSTNESS AND IMPERCEPTIBILITY PERFORMANCE OF WATERMARKING TECHNIQUE WITH DWT AND SCHUR DECOMPOSITION FOR MEDICAL IMAGES

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ABSTRACT

Developing a watermarking algorithm for a medical image is required to conserve the original visual quality and resistance ability to image attacks. The problem is that there is opposite relation between imperceptibility and robustness performance. This paper proposed a watermarking algorithm that applied discrete wavelet transfer (DWT) and Schur Decomposition to produce a watermarked image with high imperceptibility and robustness performance. In the embedding process, the DWT and Schur decomposition is used to decompose the domain of a host medical image, and the modification to hide the watermark bit is evaluated and controlled to keep the imperceptibility performance high as possible for the watermarked image. The imperceptibility, embedding capacity, and robustness are evaluated for Magnetic Resonance (MR), Computed Tomography (CT), and Positron Emission Tomography (PET) medical image modalities. The results obtained from the experiment and showed that the proposed watermark technique has high performance in three measurement terms imperceptibility, embedding capacity, and robustness. The average peak signal-to-noise ratio (PSNR) of the different six watermarked images was 73.65dB. Also have high robustness against JPEG compression, salt and pepper noise, Gaussian noise, and rotation attack.

Keywords: *Robustness, Imperceptibility, Medical Image, Discrete Wavelet Transfer, Schur Decomposition, Watermarking Technique.*

1. INTRODUCTION

The watermarking technology protects the image by including confidential data in the content without affecting the visual quality [1]. The visual quality of the watermarked image clarifies as imperceptibility performance [2]. In addition to that, to ensure the possibility of protecting property rights, the image bearing the watermark data must have the ability to protect the distraction of this data from external attacks [1]. The resistance to attacks by the watermarked image clarifies as robustness performance [3].

Different domain decomposition techniques have been used to enhance the quality of the watermarking technique in medical image watermarking. DWT as frequency transfer domain is used in the embedding process by converting the domain of the host image to frequency domain then embedding the watermark data to achieve high imperceptibility performance and protect the watermark data from images attacks [4]. DWT is used to decompose an image into four sub-bands: LowLow(LL), LowHigh(LH), HighHigh(HH), and HighLow(HL) [2]. It has been proven to be used LL sub-band achieved good imperceptibility and robustness performance[4]. The Schur Decomposition is another domain decomposition technique used in watermarking technology to provide robustness to the watermarked image against the image attacks[4]. Schur decomposition is a method of decomposing a square matrix into two matrices U and V [5]. Soualmi et al. (2019) proposed a blind and robust watermarking algorithm by combining DWT and Schur Decomposition [4]. One-level DWT performed host image blocks then selected the LL sub-band to perform Schur decomposition on it [4]. The major issue with this technique is the robust performance against image attacks.

Swaraja et al. (2020) proposed an algorithm a blind and robust watermarking algorithm for medical images. The author performed two-level DWT to transform the domain of the medical image then performed Schur decomposition with Particle Swarm Bacterial optimization algorithm to embedded dual watermarks [6].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Kumar and Jha (2019) proposed a robust watermarking algorithm by using Discrete Cosine Transform (DCT) which is another frequency transfer domain with minimum information redundancy where it is a lossy compression technique [7].

For medical images, the major issue with watermarking techniques proposed by [6] [7] is the imperceptibility performance lower than the required to avoid mistakes in medical diagnoses.

Zhang and Wei (2019) combined two transform domain techniques DWT and DCT with Singular value decomposition (SVD) to improve the robustness performance of the proposed watermarking technique under the condition of meeting the imperceptibility and security requirements [8]. The Schur decomposition is similar to SVD but the Schur decomposition needs less execution time [9].

This research proposed watermarking technique based on DWT and Schur Decomposition. The research contributions are as follows: Firstly, the DWT and Schur Decomposition are combined successively to generate a watermarked medical image with high imperceptibility, robustness,s and accepted embedding capacity performance. Secondly, the watermark data bits are embedded into the LL subband of the DWT domain, which protects the visual quality of the medical image. Thirdly, embedding the watermark data bit in the weight of the V matrix of the LL subband helps to increase the robustness performance of the watermarked image. Fourthly, using a scale factor to verify the modification process of the V matrix weight increased the imperceptibility performance. Finally, the modification process of the V matrix weight to carry the watermark bit is balanced between the imperceptibility and robustness performance. The comparative analysis conducted between our and published watermarking techniques proved the robustness and high imperceptibility performance of the proposed watermarking technique for medical images.

The paper's sections are organized as follows. Section 2 illustrates the proposed watermarking algorithm. Section 3 assesses the proposed watermarking algorithm performance and compares the performance results with the existing watermarking algorithms. Finally, the conclusion is given in Section 4.

2. WATERMARKING TECHNIQUE ALGORITHM

This section illustrates the two processes of the proposed watermarking technique embedding and extracting processes.

2.1 Watermarking Embedding Process

As shown in Figure 1, the host image divides into 8*8 non-overlapping blocks. Each block will carry one bit where it will embed in the weight of the V matrix of the LL subband of each block as illustrated in Algorithm 1. The weight of the V matrix was used in the proposed algorithm to achieve good robustness while preserving good imperceptibility performance for the watermarked image [4]. In our proposed watermarking algorithm, the V matrix weight modulation process is optimized to hold the watermark bit to improve the imperceptibility and robustness performance of the watermarked medical image.

As shown in Figure 1, all image blocks are used to include the watermark data bits and each block holds one bit. The value of the watermark bit is carried in the weight of the matrix V of the LL sub-band of the image block. The researcher used the weight of the V matrix to hide the watermark data [4] where the weight for the V matrix with size 4*4 generated from Schur decomposition of LL subband with size 4*4 of the original image block size 8*8 is defined in equation (1) below :

$$\text{Weight}=BV(1,1)+BV(2,2)+BV(2,3) \quad (1)$$

In the proposed watermarking technique, the modification process to the weight of the V matrix is enhanced to trade-off between robustness and imperceptibility performance.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

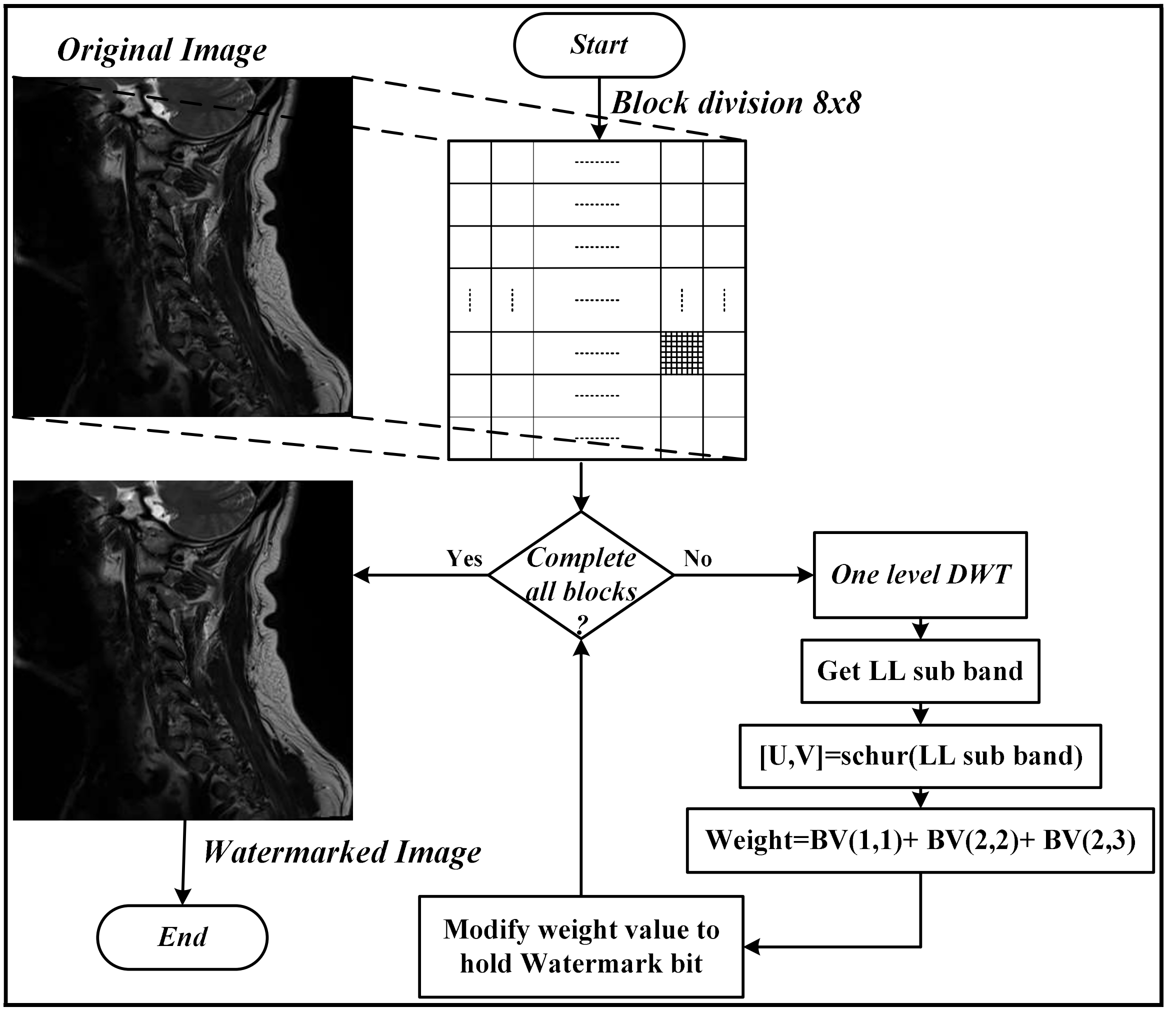


Figure 1: Flowchart of the embedding process for robustness watermarking algorithm applied DWT and Schur decomposition

As shown in Algorithm 1, the weight position 'WE_Position' is used as a scale factor to check the process of adjusting the weight of the V matrix to include the watermark bit.

The V matrix weight is subject to verification before editing because the content of the original medical image is important. The embedding process in Algorithm 1 attempts to avoid altering the content of the host image and decreasing the quality. The goal of weighing the V division matrix by 200 is to simplify the value of the container and find the constant that protects the watermark bit from image attacks.

Algorithm 1 embedding process.

```
input: Host medical image, WE_Position
Out: Watermarked image
begin
Divide the into 8*8 non-overlapping blocks
For  each block
    Apply DWT
    [U,V]=schur(LL sub band)
    w=randi([0 1])
    WE=BV(1,1)+ BV(2,2)+ BV(2,3)
    div= weight /200
    if div <= 0
    Watermark bit=0
    if w=1 and  WE >=WE_Position
        While div <=5
            BV(1,1)=BV(1,1)+1
            BV(2,2)=BV(2,2)+1
            BV(2,3))=BV(2,3)-1
    Else
        w =0
```

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

```
            end
            if w=0 and  WE < WE_Position
                While div>=4
                    BV(1,1)=BV(1,1)-1
                    BV(2,2)=BV(2,2)-1
                    BV(2,3))=BV(2,3)+1
            Else
                w=1
            end
            Watermarked LL subband=U*V*U'
            Replace original with Watermarked LL subband
            Inverse DWT for current select block
        end
    end
```

2.2 Watermark Extracting Process

In the extraction process, the algorithm extracts the watermark data from the main input which is the watermarked medical image. The extraction process is blind because there is no requirement for the original medical image to extract hidden watermark data [2].

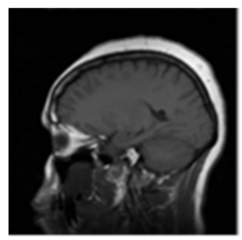
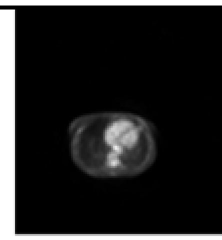
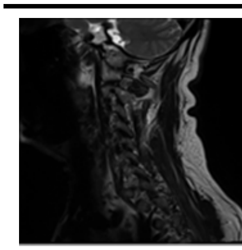
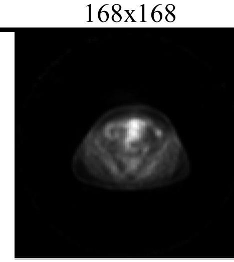
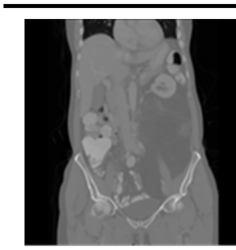
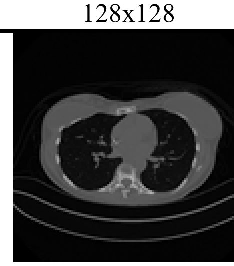
Algorithm 2 extracting process.

```
    input: Watermarked medical image
    Out: Extracted watermarked data
    begin
        Divide the input 8*8 non-overlapping blocks
        For  each block
            Apply DWT
            Get the LL sub-band
            Apply Schur decomposition on the LL sub-band
            Get the weight of the V matrix
            div= weight/200
            if  div >=3
                Watermark bit=1
            else
                Watermark bit=0
            end
        end
    end
```

3. EXPERIMENTAL RESULTS AND ANALYSIS

This section discusses the simulations, and analysis of experimental results for the proposed watermarking technique. The proposed watermarking algorithm is developed by using MATLAB, version (R2018b) where three medical image modalities were used as host medical images: MR, CT, and PET in the experiment. The modality, body part, size, and medical images are shown in Table 1. All medical image samples are grayscale. The Cancer Imaging Archive[10] and VISUS Health IT GmbH[11] are the sources of the medical image samples. The binary data 0 OR 1 where it generated randomly during the run time and WE_Position=600.

Table 1: The set of DICOM medical images.

 MR Brain 256*256	 PET Thyroid 168x168
 MR C-spine 320*320	 PET Lung 128x128
 CT Abdomen 512x512	 CT LUNG 512x512

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The developed watermarking algorithm is evaluated by measuring imperceptibility, embedding capacity, and robustness performance. The Peak Signal-To-Noise Ratio (PSNR) is the equation used to evaluate the imperceptibility performance of watermarked image by measuring its visual quality in comparison to the original image[12]. The PSNR value of the watermarked to the original image is computed as follows:

$$PNSR=10*\log10(R2/MSE) \qquad (2)$$

Where MSE is computed for watermarked and original image as follows:

$$MSE=(\sum i*j(I(i,j)-I_w(i,j))^{\wedge}2\ )/(i*j) \qquad (3)$$

The Normalized Correlation Coefficient (NCC) is the equation used in the experiment to measure the similarity between the extracted and original watermark data[12] as follows:

$$NCC=(\sum\_i*j(W(i,j)*WE(i,j)))/(\sum i*j(W(i,j)2*WE(i,j)2\ )\ ½ \qquad (4)$$

Embedding capacity performance is the size of watermark data embedded in the watermarked image [3].

3.1 Simulation of the watermarking process

The points below illustrate the process of including the watermark bit in the matrix V of the LL subband of the image block where it is shown in Figure 2 of the MR BRAIN image with the watermark bit equal to 1 and WE_Position=600.

1. Use Equation (1) to compute the Weight the matrix V (B) in Figure 2.
   Weight=(884.2415)+(-79.0254)+(15.0341)= 790.1820;
2. div computes by below:
   div=790.1820/200=3.9509

884.2415	225.9702	142.6153	-34.4874
0	-79.0254	15.03406	75.52863
0	0	41.16985	31.45004
0	0	0	12.11404

(A)

954.2415	225.9702	142.6153	-34.4874
0	-9.02539	-54.9659	75.52863
0	0	41.16985	31.45004
0	0	0	12.11404

(B)

Figure 2: (A) Original and (B) watermarked of the V Matrix of the LL Subband of the Image Block for MR Image when Watermark Bit Equals 1 and WE_Position=600

3. div value >0 and WE≥WE_Position
4. While div <=5 do the below:
   a. Weight up
      BV(1,1)= BV(1,1)+1
      BV(2,2)= BV(2,2)+1
      BV(2,3)= BV(2,3)-1
   b. Weight=BV(1,1)+BV(2,2)+ BV(2,3)
   c. div= Weight /200/,

The while loop will continue to increase the weight value of the V matrix of the LL subband of the image block until equal to 5.00091020978081 and the watermarked V matrix values updates as shown in Figure 2 (B).

3.2 Algorithm Performance Analysis

Imperceptibility Performance

The PSNR value for the watermarked medical image should be > 40 dB to avoid mistakes in medical diagnoses [13]. Therefore, from Table 2, the PSNR values indicate that imperceptibility performance achieved by the proposed watermarking algorithm is high.

Embedding Capacity Performance

As stated in Algorithm 1 in section 2, the number of the watermark bit depends on the original image size because the embedding process in section 2 divides it into 8*8 non-overlapping blocks where each block carries one bit.

Table 2: The medical image modality and its embedding capacity in bits, PSNR of the watermarked image, and NCC of the extracted watermark data.

Modality	bits	PSNR	NCC
MR Brain	1024	72.1415	1
MR Cspine	1600	69.1869	0.9995
PT Thyroid	441	78.5094	1
PT Lung	256	76.0162	1
CT Lung	4096	68.2729	0.9998
CT Abdomen	4096	77.7555	1

Robustness Performance

Various image attacks were applied in the experiment JPEG compression, salt and pepper noise, Gaussian noise, and rotation to evaluate the robustness performance. The watermarked image is attacked by image attacks then the watermark data is extracted from the attacked watermarked image to evaluate the robustness by computing the NCC between the original and extracted watermark data.

If the NCC value is closer to 1, the watermarked image has robustness performance against image attack[10]. Table 3 shows the NCC values for MR Cspine, PT Thyroid, and CT Abdomen. The NCC values prove the proposed algorithm achieved high robustness performance.

Table 3: The robustness performance of the watermarked image.

Modality	Robustness(NCC) JPEG QF = 50	Salt and pepper d = 0.01	Gaussian m = 0, v = 0.01	Rotati 15°
MR Cspine	0.97	0.99	0.98	0.94
PT Thyroid	1	1	0.99	0.79
CT Abdomen	0.99	0.99	0.99	0.91

3.3 Performance Comparative Analysis

This section compares the performance of the proposed with the existing watermarking algorithms in [4], [7], [8], [15] as shown in Table 4 and Table 5. Where it is compared with the experimental results of CT medical images got by [8], [15] and MR medical images got by [4], [7].

Imperceptibility Performance

As shown in Table 4, the PSNR value for the watermarked image in [4], [7], [8], [15] papers used medical images as a host image was 36.83, 36.3563, 46.9532, and 45.8225 respectively, and the PSNR for the proposed watermarking Algorithm is 68.2729 for CT image and 71.4677 for MR image. This indicates that our proposed watermarking algorithm has high imperceptibility performance.

Embedding Capacity Performance

As explained in section 2, the number of the watermark bit depends on the original image size because the embedding process divides it into 8*8 non-overlapping blocks where each block carries one bit. For the MR medical image with size 256*256, the number of watermark data bits that can be carried by it is equal (256*256)/(8*8) = 1024.

Table 4: Compare the imperceptibility performance with [4], [7], [8], [15]

Algorithm	Modality	PSNR
Proposed Algorithm	CT	68.2729
[8]		46.9532
[15]		45.8225
Proposed Algorithm	MR	71.4677
[4]		36.83
[7]		36.3563

As shown in Table 5 and Table 6, the proposed algorithm has equal embedding capacity with [4], [7], and low than [8], [15] as shown in Table 4 and Table 5.

Robustness Performance

The NCC values are given in Table 4 and Table 5 under JPEG compression, salt and pepper, Gaussian noise, and rotation attack. The proposed algorithm has high robustness performance against salt and pepper, and rotation attacks than [4], [7], [8], [15] and has high robustness performance against JPEG compression than [7].

Table 5: Compare the embedding capacity and robustness performance with [4], [7], [8], [15] *for MR image.*

Performance assessment	Algorithm [7]	[4]	Proposed Algorithm
Host image size	256*256	256*256	256*256
Watermark data bits	1024	1024	1024
Attacks	**NCC**		
JPEG Compression (QF = 90)	0.92	--	0.97
JPEG Compression (QF = 50)	--	0.98	0.97
Salt and pepper (d = 0.01)	--	0.97	0.9976
Rotation 0.1°	0.92	0.64	1

Table 6: Compare the embedding capacity robustness performance with [4], [7], [8], [15] *for CT image.*

Performance assessment	Algorithm		
	[8]	[15]	Proposed Algorithm
Host image size	512*512	512*512	512*512
Watermark data bits	16,384	--	4096
Attacks	NCC		
JPEG Compression (QF = 50)	--	0.9347	0.9033
JPEG Compression (QF = 10)	0.99	--	0.9507
Salt and pepper (d = 0.01)	0.98	--	0.9906
Salt and pepper (d = 0.001)	--	0.9077	0.9989
Rotation 0.45°	0.99	--	0.9989

4. CONCLUSION

This research proposed watermarking technique that used DWT and Schur decomposition where the DWT sub-band decomposes by the Schur decomposition to embed the watermark bits. The robustness of the proposed watermarking technique was evaluated under various attacks. Also, the algorithm is verified in terms of the imperceptibility of watermarked images. The imperceptibility performance of the proposed watermark technique is high where the average PSNR value is 73.65dB. The NCC value indicates the robustness of the watermarked image attacks. In future works, the optimization algorithm will use to find optimal scale factors for generating watermarked images with high imperceptibility and robustness performance.

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