International Journal of Digital Crime and Forensics
Volume 11 • Issue 2 • April-June 2019

A FRT - SVD Based Blind Medical Watermarking Technique for Telemedicine Applications

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ABSTRACT

In this article, a blind and robust medical image watermarking technique based on Finite Ridgelet Transform (FRT) and Singular Value Decomposition (SVD) is proposed. A host medical image is first transformed into 16 × 16 non-overlapping blocks and then ridgelet transform is applied on the individual blocks to obtain sets of ridgelet coefficients. SVD is then applied on these sets, to obtain the corresponding U, S and V matrix. The watermark information is embedded into the host medical image by modification of the value of the significant elements of U matrix. This proposed technique is tested on various types of medical images such as X-ray and CT scan. The simulation results revealed that this technique provides better imperceptibility, with an average PSNR being 42.95 dB for all test medical images. This technique also overcomes the limitation of the existing technique which is applicable on only the Region of Interest (ROI) of the medical image.

KEYWORDS

Arnold Scrambling, Blind Watermarking, Finite Ridgelet Transform (FRT), Medical Image, Singular Value Decomposition (SVD)

1. INTRODUCTION

In the last few years, medical treatments and diagnosis of the patients are being solved with the support of a variety of medical data such as images or signals. While the examples of medical images which are widely used are Magnetic Resonance Imaging (MRI), X-ray, Computerized Tomography (CT) and Ultrasound (US), the examples of 1-D medical signals are ECG and EEG signals. Nowadays, it has become a common practice to share medical data among doctors and radiologists for better diagnosis, health solution, and treatment. Transferring medical images over a transmission medium is referred to as telemedicine (American Hospital Association, 2015; Yassin, 2015). The telemedicine aids in emergency treatment, home monitoring, military applications and medical education (Yassin, 2015) to name a few. Security of medical images becomes necessary when they are transferred over any open access network. Corruption or modification of medical images by someone or some process leads to serious health issues for any individual. There is in fact high probability for the medical images being corrupted or modified by various intentional and unintentional processing during storage or transmission over a medium. While various techniques such as cryptography and steganography are available for protecting medical images, the digital watermarking technique is the proven solution for copyright protection (Borra et al., 2017; Thanki et al., 2017; Lakshmi and Borra, 2016; Borra and Lakshmi, 2015; Borra and Swamy, 2014; Borra et al., 2012; Borra and Swamy, 2012; Thanki et al., 2011; Borra and Swamy, 2009).

DOI: 10.4018/IJDCF.2019040102

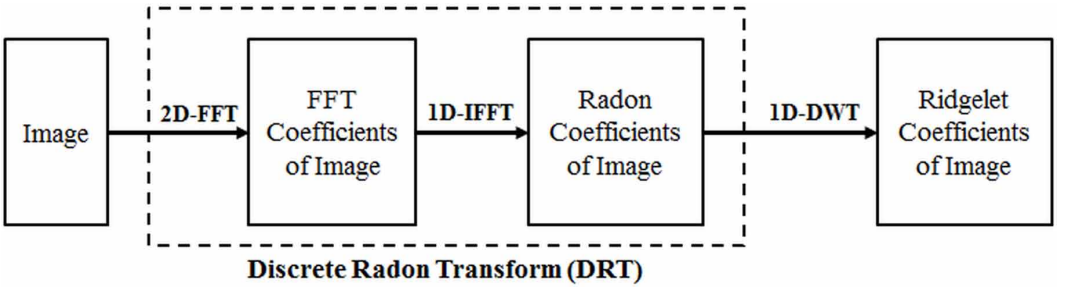
1.1. Related Work

In the last few years, various watermarking techniques based on Singular Value Decomposition (SVD) and its combinations with other transforms have been proposed for security of medical image. F. Thakkar (Thakkar and Srivastava, 2017) has used SVD-DWT transform coefficients for embedding watermark information into the U matrix of SVD. In this technique, first column second row value and first column third row value of U block of LL subband of the host medical image is modified according to watermark bits. This technique is modified version of Su technique (Su et al., 2013), wherein the same U block is used for watermark bit embedding. A major limitation of the Thakkar technique is that it is only applicable on Region of Interest (ROI) of medical images or high contrast medical images. Also, extraction of watermark data resulted in poor quality, less imperceptibility, and poor robustness. A. Singh (Singh et al., 2014) has proposed two watermarking techniques based on the combinations of DWT, SVD, and cryptography for the security of medical images. In this technique, authors used three different error correcting codes: Hamming, Bose-Chaudhuri-Hocquenghem (BCH) and Reed-Solomon code for encoding watermark data. Later, this encoded watermark data is embedded into wavelet coefficients of the medical image in wavelet-based technique, and singular values of the medical image in SVD based technique, respectively. Authors suggested that Reed-Solomon based encoded watermark data performed better than other two error correcting codes. N. Venkatram (Venkatram et al., 2014) has proposed 2D Lifting Wavelet Transform (LWT) and SVD based medical image watermarking technique. N. Dey (Dey et al., 2012a, 2012b; proposed a hybrid medical image watermarking technique using three image processing transforms such as DCT, DWT, and SVD. A. Singh (Singh, 2015) proposed hybrid watermarking techniques for medical image protection. These techniques are designed by combining DWT, SVD and spread spectrum approach.

After a detailed survey of SVD based medical image watermarking techniques, it is observed that most of the existing watermarking techniques are less imperceptible and less robust. This paper aims at overcoming the limitations of existing techniques, in particular, Thakkar technique (Thakkar and Srivastava, 2017) where it is only applicable on Region of Interest (ROI) of medical images, or for high contrast medical images. Thus, a new hybrid watermarking technique is designed and proposed using a combination of Finite Ridgelet Transform (FRT) and SVD is this paper. The other motivation for proposing this technique is that a very less number of techniques are designed and implemented using Finite Ridgelet Transform (FRT) for protection of medical images. The proposed technique is more imperceptible and more robust against geometric attacks, signal processing attacks and JPEG compression attack compared to existing techniques.

In the proposed technique, a host medical image is first decomposed into 16×16 non-overlapping blocks and then Finite Ridgelet Transform (FRT) is applied on individual blocks to obtain sets of ridgelet coefficients of medical image. Singular Value Decomposing is then applied on these sets, so as to obtain the corresponding U, S, and V matrix. The watermark information is inserted into the host medical image by modification of the value of the significant elements of U matrix to get watermarked medical image. In the proposed technique, watermark information is inserted in such a way that its blind extraction is possible at extraction side. An Arnold scrambling technique is used to secure watermark information before inserting it into the host medical image. The combination of above mentioned techniques like FRT, SVD and Arnold Scrambling in proposed watermarking technique provides more security, more imperceptibility and blind extraction of watermark information. The rest of the paper is organized as follows: in section 2, preliminaries used in the proposed technique are given. Section 3 presents the proposed technique, whereas experimental results and discussion are given in section 4. The performance analysis of proposed technique for color medical images is given in section 5. Finally, section 6 concludes the paper.

Figure 1. Basic steps for Finite Ridgelet Transform (FRT)



2. TECHNICAL INFORMATION

In this section, brief information on Finite Ridgelet Transform (FRT) and Singular Value Decomposition (SVD) and their usefulness in watermarking is provided.

2.1. Finite Ridgelet Transform (FRT)

D. Donoho (Donoho, 2001) has introduced the continuous ridgelet transform (CRT) in 2001 as the orientation of 1D wavelet function by constant lines and radial directions. Ridgelet transform (Alzubi et al., 2011; Do and Vetterli, 2000; Candes and Donoho, 2000; Candes, 1998) has proved its effectiveness over wavelets. The traditional wavelet transform does not separate smooth information along with edges in the images (Alzubi et al., 2011; Candes, 1998). While wavelet transform represents an image with point singularities value, ridgelet transform represents an image with line singularities. The finite ridgelet transform (FRT) involves two steps: Calculation of Discrete Radon Transform (DRT) followed by application of 1D wavelet transform. In turn, discrete radon transform is also calculated in two steps: Calculation of 2D Fast Fourier Transform (FFT) followed by application of 1D Inverse Fast Fourier Transform (IFFT) on each of the 32 radial directions of the radon projection. The DRT represents the image as a set of projections of different angles in the projection space. For digital images, a projection is calculated by summarization of all data values that lie within specified lines which are defined by finite geometry (He, 2006).

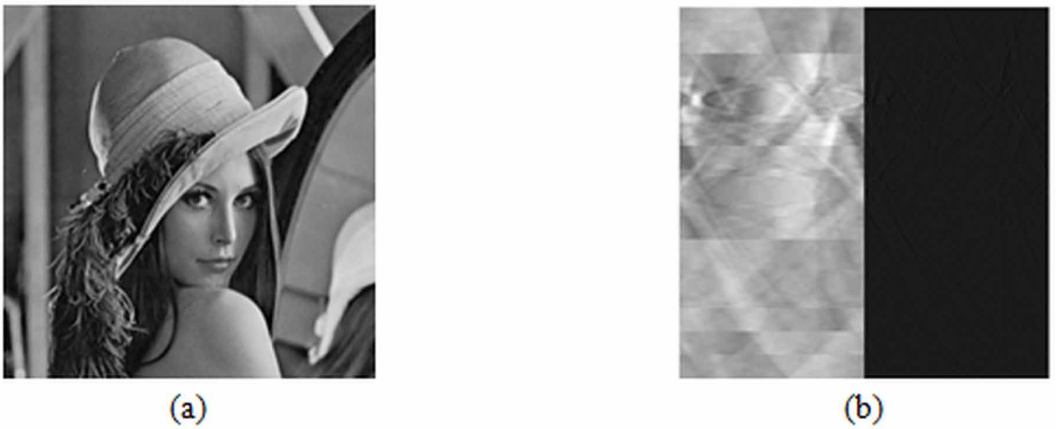
The implementation of ridgelet transform depends on the implementation of radon and wavelet transforms (Dettori and Semler, 2007). The wavelet transform is applied on each output of radon projection. Figure 1 shows basic finite ridgelet transform (FRT) where FRT has converted a line singularity into point singularity. Finally, the wavelet transform is applied for effective segmentation of point singularity in the Radon domain. Figure 2 shows the ridgelet transform coefficients of the image.

When FRT is applied to an image of size N×N, the result is an image of size 2N×2N containing ridgelet coefficients. In watermarking applications, the ridgelet coefficients of the host image are modified according to watermark bits. For the watermarking technique to be secure, ridgelet coefficients of host image are chosen in such a way that it results in terms of imperceptibility and robustness. The advantage using of FRT in watermarking is that it improves the embedding capacity of watermarking technique.

2.2. Singular Value Decomposition (SVD)

Singular Value Decomposition (SVD) (Thakkar and Srivastava, 2017; Su et al., 2013) is a numerical technique of diagonaling the matrices. When SVD is applied to an image of the size of M×N, three matrices are obtained, namely U, V and S. The U and V matrices are called orthogonal matrices of size M×M and N×N respectively. S matrix is a diagonal matrix of the size of M×N. One example of the SVD process is demonstrated in Figure 3(a). In this Figure, a sample block with a size of 4×4 is chosen from Lena image and is denoted as matrix A. The resultant U, S, and V matrices obtained

Figure 2. (a) Lena image (b) Its ridge transform coefficients



after direct application of SVD are shown in Figure 3 (a). The U matrix obtained after application of SVD on the ridgelet coefficients of the image is shown in Figure 3 (b). It is to be noted that the first column elements of U matrix are nearly equal. This observation has led to the selection of elements: U (1, 1) and U (2, 1) for watermark embedding in the proposed watermarking technique. Here, U (1, 1) is element of first row and first column of U matrix.

For proper justification of choosing the elements of U block in proposed technique, Normalized Correlation (NC) (Kutter and Petitcolas, 1999) of the two elements U (1, 1) and U (2, 1) is calculated for a variety of images and are compared with the NC values which resulted from other existing watermarking techniques (Thakkar and Srivastava, 2017; Su et al., 2013) respectively. The comparison is listed in Table 1, where it is concluded that while the average NC value of proposed technique is equal to 1 for every image, the other techniques has led to an NC value of 0.9798 on an average.

The similarity of U blocks in proposed technique provides better extraction of watermark information and reduces some computational complexity of existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013). The swapping of U blocks is performed and required before watermark information is inserted into medical image in in the existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013). This process is eliminated in the proposed technique.

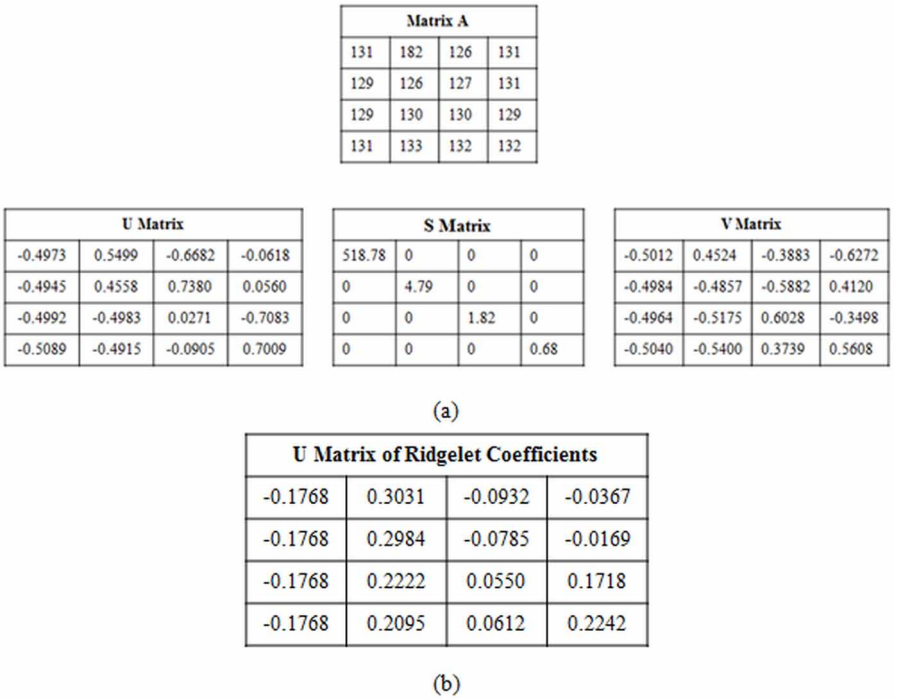
2.3. Arnold Scrambling

In the proposed watermarking technique, Arnold scrambling (Roy and Pal, 2017) is used to encrypt watermark before embedding it into the host medical image so that attacker can't extract watermark information from the medical image. The resultant chaotic image is secure and can't be extracted without the knowledge of the scrambling algorithm and secure key.

3. PROPOSED TECHNIQUE

In this paper, a blind watermarking technique based on FRT – SVD is proposed, in order to make the watermarking technique more imperceptible and robust against different attacks. In this technique, Arnold scrambling is used to provide security to watermark data before embedding it in the host medical image. The host medical image to be protected is first divided into non-overlapping blocks of size 16×16. FRT is then applied on non-overlapping blocks to get ridgelet coefficients of the medical image. Following the FRT is SVD, which results in a U matrix. Two elements of the first column of this U matrix are modified according to scrambled watermark bits and by using a threshold value "T". Blind extraction of watermark bits is made possible in proposed technique by comparing the pair of

Figure 3. (a) Example of SVD on block (b) U matrix of ridgelet coefficients of block



Matrix A

131	182	126	131
129	126	127	131
129	130	130	129
131	133	132	132

U Matrix

-0.4973	0.5499	-0.6682	-0.0618
-0.4945	0.4558	0.7380	0.0560
-0.4992	-0.4983	0.0271	-0.7083
-0.5089	-0.4915	-0.0905	0.7009

S Matrix

518.78	0	0	0
0	4.79	0	0
0	0	1.82	0
0	0	0	0.68

V Matrix

-0.5012	0.4524	-0.3883	-0.6272
-0.4984	-0.4857	-0.5882	0.4120
-0.4964	-0.5175	0.6028	-0.3498
-0.5040	-0.5400	0.3739	0.5608

(a)

U Matrix of Ridgelet Coefficients

-0.1768	0.3031	-0.0932	-0.0367
-0.1768	0.2984	-0.0785	-0.0169
-0.1768	0.2222	0.0550	0.1718
-0.1768	0.2095	0.0612	0.2242

(b)

Table 1. NC values of element values of U (1, 1) and U (2, 1) after SVD

Test Image	Proposed Technique	Existing Techniques (Thakkar and Srivastava, 2017; Su et al., 2013)
Lena	1.00	0.9934
House	1.00	0.9966
Peppers	1.00	0.9673
F16	1.00	0.9921
Baboon	1.00	0.9709
Sailboat	1.00	0.9879
Barbara	1.00	0.9982
Couple	1.00	0.9323
Average	**1.00**	**0.9798**

elements: U (1, 1) and U (2, 1) extracted from the blocks of the medical image. The block diagram of proposed embedding and extraction processes is given in Figure 4 and Figure 5, respectively. The steps involved in watermark embedding and extraction are given in the following subsections.

Figure 4. Proposed watermark embedding process

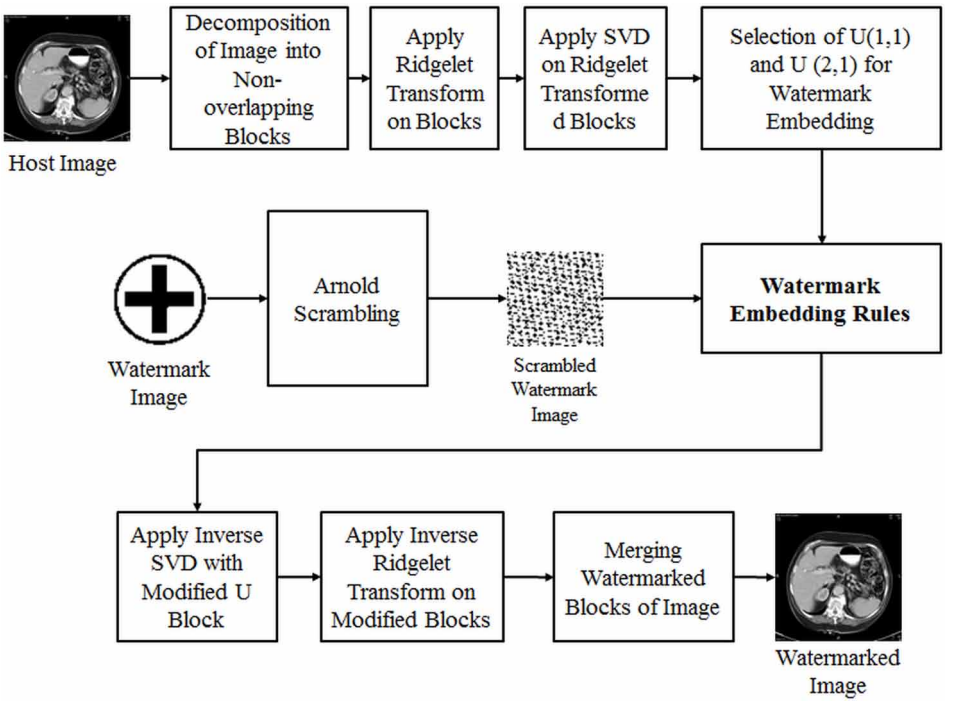
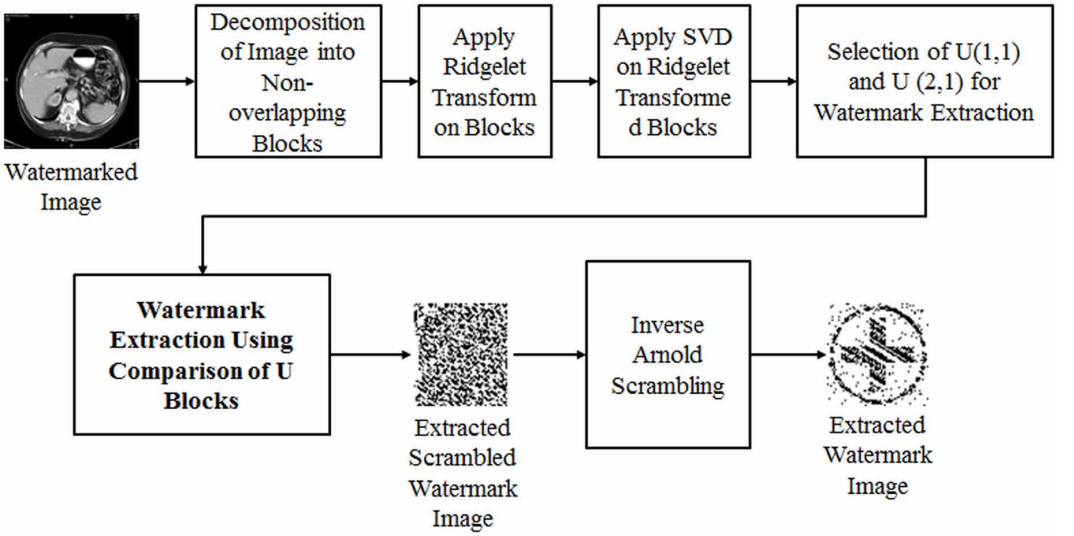


Figure 5. Proposed watermark extraction process



3.1. Watermark Embedding Process

A watermark bit is embedded into FRT-SVD of host medical image using swapping of U block values. The algorithm for watermark embedding is given below:

Step 1: Calculate the size of watermark image.
Step 2: Apply Arnold scrambling on the watermark image to generate scrambled watermark information in terms of the binary sequence.
Step 3: Calculate the size of the host medical image.
Step 4: Convert host medical image into non-overlapped blocks of size 16×16.
Step 5: Apply FRT on the non-overlapped block to get ridgelet coefficients of host medical image. Then apply SVD on ridgelet coefficients to get U matrix, S matrix and V matrix of host medical image.
Step 6: Choose U (1, 1) and U (2, 1) value of U matrix for watermark bit embedding. Embed each bit of scrambled watermark in each U matrix of ridgelet block of host medical image based on the following conditions:

- If scrambled watermark bit is zero then:

$$\begin{aligned} U(2,1) &= U(2,1) + (T / 2); \\ U(1,1) &= U(1,1) - (T / 2); \end{aligned} \tag{1}$$

- If scrambled watermark bit is one then:

$$\begin{aligned} U(2,1) &= U(2,1) - (T / 2); \\ U(1,1) &= U(1,1) + (T / 2); \end{aligned} \tag{2}$$

where, T is a threshold value.

- Repeat the above procedure for all scrambled watermark bits.

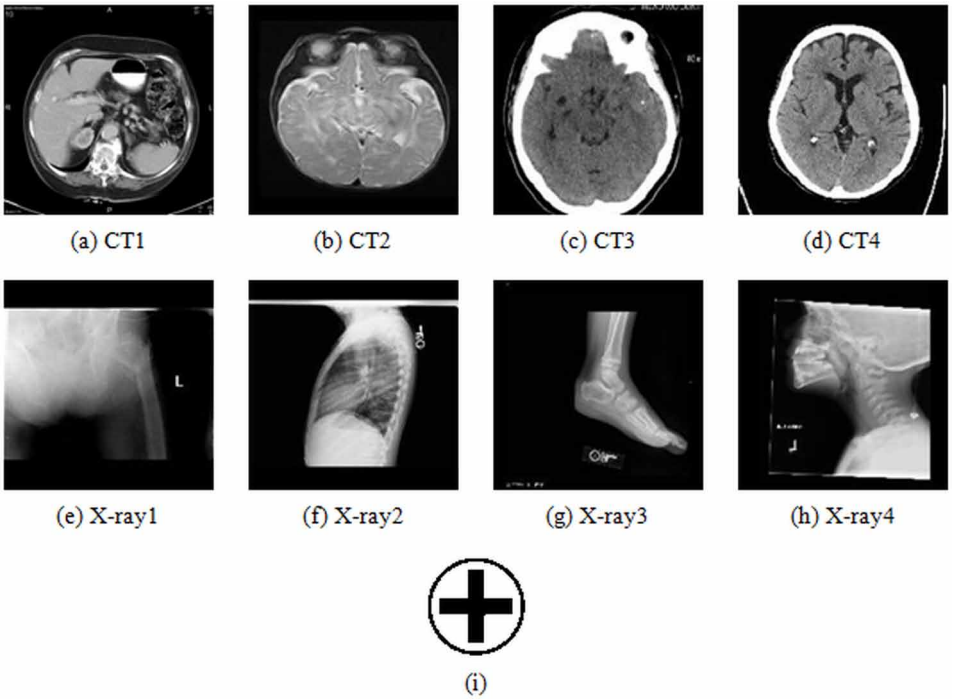
Step 7: Apply inverse SVD on the modified U matrix with other two matrices (S and V) to get modified ridgelet coefficients of host medical image.
Step 8: Apply inverse FRT on modified ridgelet coefficients to get watermarked medical image.

3.2. Watermark Extraction Process

In this technique, a scrambled watermark bit is extracted blindly using the comparison of U block values of watermarked medical image. The algorithm for watermark extraction is given below:

Step 1: Calculate the size of watermarked medical image.
Step 2: Convert watermarked medical image into non-overlapped blocks with a size of 16×16.
Step 3: Apply FRT on each non-overlapped block to get the corresponding ridgelet coefficients. Then apply SVD on ridgelet coefficients to get U, S and V matrices of watermarked medical image.
Step 4: Choose U (1, 1) and U (2, 1) value of U matrix for watermark bit extraction. Each watermark bit is extracted from U matrix of ridgelet block of watermarked medical image based on following conditions:

Figure 6. (a) – (h) Test host medical images; (i) Watermark image



If U (2, 1) > U (1, 1)
Scrambled watermark bit = 0;
Else
Scrambled watermark bit = 1;

Step 5: Apply inverse Arnold scrambling to get actual watermark information at recovering side.

4. RESULTS AND DISCUSSION

The proposed technique is tested and analyzed by various medical images such as X-ray and CT. The size of these images is 1024×1024 pixels. The 100 test host medical images are taken from the MedPix™ Medical Image Database and few sample medical images are shown in Figure 6 (a) – (h). A binary watermark image (logo) with more smooth details is used for testing. The dimension of watermark image is 64×64 pixels and is shown in Figure 5 (i). The implementation of the proposed technique is done on the laptop 2 GHz core two Duo processor with 2 GB RAM using MATLAB 2013a software.

To embed watermark bits, each host medical image is converted into non-overlapping blocks of size 16×16. Then forward FRT is applied to the individual blocks to get ridgelet transform coefficients blocks of size of 32×32. SVD is applied to ridgelet blocks to obtain values of U (1, 1) and U (2, 1) of U matrix block, wherein the scrambled watermark bits can be embedded. The scrambled watermark bits are obtained by applying forward Arnold scrambling on watermark information. After getting the modified U matrix block, inverse SVD is applied to U blocks to obtain modified ridgelet transform coefficient blocks. Then inverse FRT is then applied on these modified ridgelet transform coefficients of blocks to get watermarked blocks of image. Finally, blocks are reconstructed into image to get

watermarked medical image. For extraction of watermark from watermarked medical image, first get U (1, 1) and U (2, 1) of U matrix of ridgelet transform blocks. The comparison of these blocks is performed to extract scrambled watermark bits at extraction side. Finally, inverse Arnold scrambling is applied on the extracted scrambled watermark bits to get watermark information.

In this proposed technique, a medical image of size 1024×1024 pixels are tested as host image and FRT is applied to it to get its ridgelet coefficients. The ridgelet coefficients with size 2048×2048 pixels are converted into 4096 non-overlapping blocks each of size 16×16. The U matrix values U (1, 1), U (2, 1) of each block are obtained by application of SVD on it. The watermark image of size 64×64 pixels is converted into a vector of size 4096. This watermark image is converted into scrambled watermark bits by application of Arnold scrambling on it. Then according to scrambled watermark bits, the values of U (1, 1) and U (2, 1) are modified by threshold value. The modified 4096 blocks of host medical image with scrambled watermark bits are obtained after watermark embedding process. The inverse SVD is applied to modified U matrix values with S matrix, and V matrix to get modified Ridgelet coefficients of size 2048×2048. Then inverse FRT is applied to modified ridgelet coefficients to get watermarked medical image. Here, one watermark bit is embedded into each block of the host medical image. In this proposed technique, the size of host medical image is 1024×1024 and block size is 16. Thus, the proposed technique can embed a maximum watermark image of size 64×64 pixels.

4.1. Performance Measures

Peak Signal to Noise Ratio (PSNR) is used to measure imperceptibility between original host medical image and watermarked medical image. The PSNR is given in Equation 5. PSNR depends on Mean Square Error (MSE) which is an error between the original image and processed image. The MSE is calculated using Equation 6. The MSE is measured in real value while PSNR is measured in dB value. A high value of PSNR indicates more imperceptibility of the technique:

$$PSNR = 10 \times \log\left(\frac{255^2}{MSE}\right) \tag{3}$$

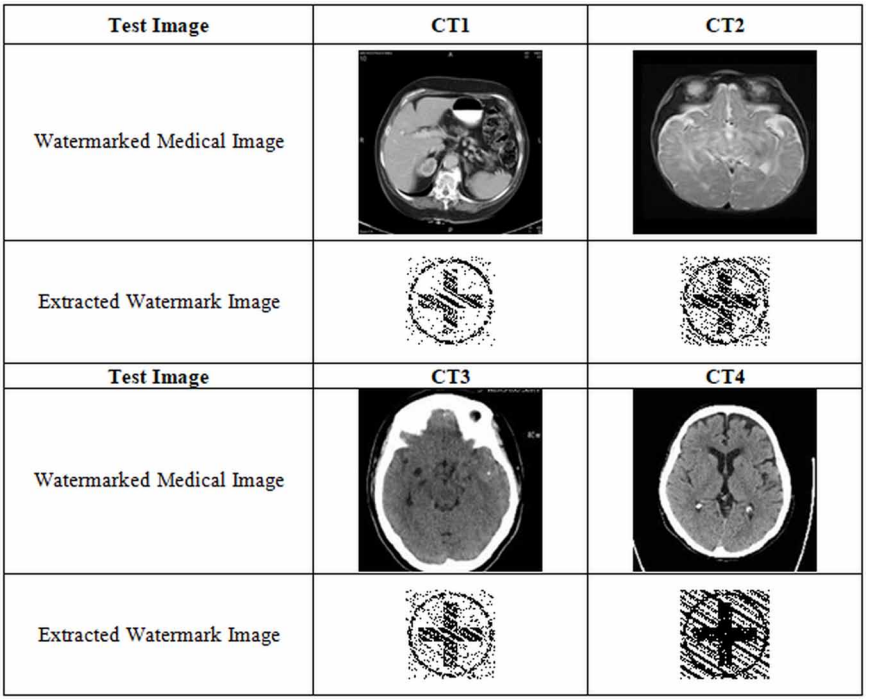
$$MSE = \frac{1}{M \times N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \Big(H(x,y) - WH(x,y)\Big)^2 \tag{4}$$

where, *H* is the original host medical image and *WH* is watermarked medical image, respectively.

The robustness of watermarking technique can be measured by normalized correlation (NC). The normalized correlation can be calculated using Equation 7. NC measures the similarity between original watermark image and extracted watermark image. The robustness of any watermarking technique is high if NC value is close to one:

$$NC = \frac{\sum_{x=1}^{M} \sum_{y=1}^{N} w(x,y) \times w*(x,y)}{\sum_{x=1}^{M} \sum_{y=1}^{N} w^2(x,y)} \tag{5}$$

Figure 7. Watermarked CT images and extracted watermark images using proposed technique with threshold *T* value = 2



where, w is original watermark image and w^* is extracted watermark image. Using above measures, imperceptibility test and robustness test of proposed technique are performed on various medical images for performance evaluation.

4.2. Imperceptibility Test

For imperceptibility test, PSNR is calculated between original host medical image and watermarked medical image, and is then compared with the existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013). Figure 7 and Figure 8 show the quantitative results of proposed technique for a different set of host medical images. Results include watermarked medical images and extracted watermark images. The watermark embedding process is performed by a constant threshold T with value 2. The threshold affects the quality of watermarked medical images and extracted watermark images. Here, the range of threshold value T varies from 2 to 11, as per Human Visual System (HVS) property of watermarking requirements. The results in Figure 7 and Figure 8 show the extracted watermark image has some degradation. This happens due to comparisons of hybrid coefficients used in embedding the watermark bits. Figure 9 shows the extracted watermark images using different threshold values. The corresponding PSNR and NC values are tabulated in Table 2.

The results in the Table 2 indicate that when threshold increases, the quality of extracted watermark images also increases. But quality of watermarked medical image decreases. The results also show that this proposed technique performs similar for threshold value from 2 to 11 as per HVS requirements of watermarking technique.

In the proposed technique, Arnold scrambling technique is used for security of watermark image before embedding into the host medical image. The encrypted watermark image and decrypted watermark image is generated using secret key at watermark embedding process and extraction process, respectively. In this proposed technique, the value of secret key is chosen as 45. Figure 10

Figure 8. Watermarked X-ray images and extracted watermark images using proposed technique with threshold *T* value = 2

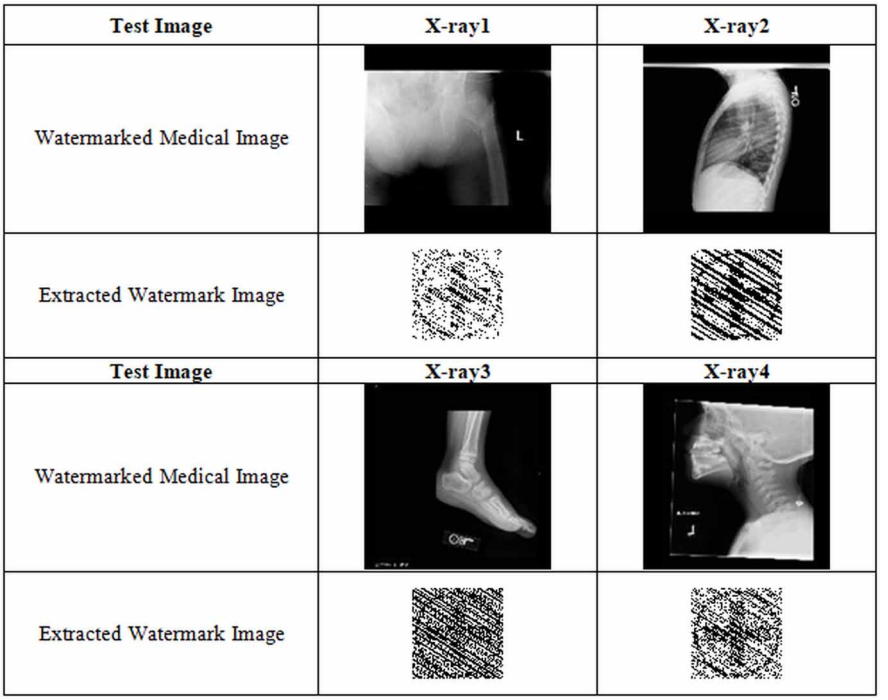


Figure 9. Extracted watermark images using different threshold *T* values

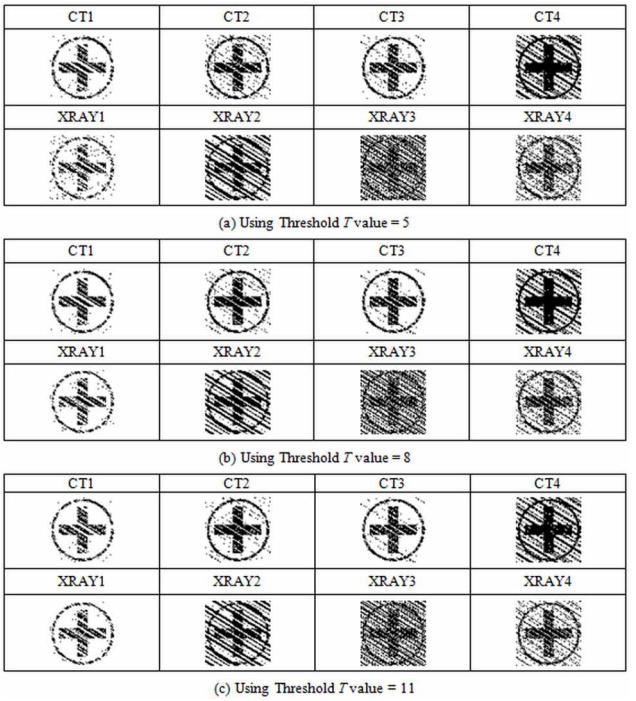


Table 2. PSNR (dB) and NC values of proposed technique using different threshold *T* value

Test Medical Image	Using Threshold *T* value = 2		Using Threshold *T* value = 5		Using Threshold *T* value = 8		Using Threshold *T* value = 11	
	PSNR (dB)	NC	PSNR (dB)	NC	PSNR (dB)	NC	PSNR (dB)	NC
CT1	44.51	0.9461	36.55	0.9801	32.47	0.9904	29.70	0.9933
CT2	49.95	0.8096	41.99	0.9004	37.91	0.9284	35.14	0.9504
CT3	44.27	0.8855	36.31	0.9518	32.23	0.9681	29.47	0.9727
CT4	42.95	0.5830	34.97	0.6227	30.91	0.6333	28.15	0.6369
X-ray1	50.56	0.8727	42.60	0.9550	38.51	0.9862	35.75	0.9915
X-ray2	47.01	0.6089	39.05	0.6394	34.97	0.6500	32.20	0.6532
X-ray3	51.92	0.4720	43.96	0.5064	39.87	0.5443	37.11	0.5585
X-ray4	46.77	0.6947	38.81	0.7635	34.73	0.7897	31.96	0.8191

shows the encrypted watermark image at the input of watermark embedding process and extracted encrypted watermark image at watermark extraction process.

The corresponding PSNR values are tabulated and compared in Table 3. The comparison of techniques is performed using threshold value T as 2 and without application of any watermarking attacks. The results of existing techniques are generated using same database mentioned in Figure 6. The maximum PSNR of watermarked medical images of proposed technique is 51.92 dB, while the maximum value of PSNR of watermarked medical images of existing techniques is 31.17 dB (Thakkar and Srivastava, 2017) and 39.21 dB (Su et al., 2013), respectively. This indicates the improvement in the quality of watermarked medical images, and thereby imperceptibility in the proposed technique. The NC values of extracted watermark images are also tabulated and compared in Table 3. The maximum value of NC for the proposed technique is around 0.946, while the maximum value of NC of existing techniques is 0.6676 (Thakkar and Srivastava, 2017) and 0.6668 (Su et al., 2013), respectively. This indicates the improvement in the quality of extracted watermarks.

Also, this proposed techniques and existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013) are tested over medical image database which contains 100 different CT and XRAY images. The average results obtained from the 100 tested medical images is tabulated and compared in Table 4. The average PSNR of watermarked medical images of proposed technique is around 47.64 dB,

Figure 10. (a) Encrypted watermark image using Arnold Scrambling (b) Extracted encrypted watermark image

Table 3. Imperceptibility test comparison of proposed technique and existing technique

Test Medical Image	Su Technique (Su et al., 2013)		Thakkar Technique (Thakkar and Srivastava, 2017)		Proposed Technique	
	PSNR (dB)	NC	PSNR (dB)	NC	PSNR (dB)	NC
CT1	32.17	0.4550	26.29	0.4180	44.51	0.9461
CT2	36.03	0.6668	30.30	0.3512	49.95	0.8096
CT3	33.56	0.6209	27.68	0.6676	44.27	0.8855
CT4	33.28	0.4903	27.29	0.0476	42.95	0.5830
X-ray1	37.11	0.5060	31.17	0.0080	50.56	0.8727
X-ray2	34.26	0.5051	25.32	0.5544	47.01	0.6089
X-ray3	39.21	0.3011	28.91	0.3656	51.92	0.4720
X-ray4	33.51	0.5338	28.11	0.0080	46.77	0.6947

Table 4. Imperceptibility test comparison of proposed technique and existing technique for 100 test medical images

No. of Test Medical Images	Su Technique (Su et al., 2013)		Thakkar Technique (Thakkar and Srivastava, 2017)		Proposed Technique	
	PSNR (dB)	NC	PSNR (dB)	NC	PSNR (dB)	NC
100	29.52	0.3082	33.34	0.4615	47.64	0.8044

while the average value of PSNR of watermarked medical images of existing techniques is around 33.34 dB (Thakkar and Srivastava, 2017) and 29.52 dB (Su et al., 2013), respectively. The NC values of extracted watermark images are also tabulated and compared in Table 3. The average value of NC for the proposed technique is around 0.8044, while the average value of NC of existing technique is around 0.4615 (Thakkar and Srivastava, 2017) and 0.3082 (Su et al., 2013), respectively. The results show that this proposed technique is performs better than the existing techniques in terms of imperceptibility.

4.3. Robustness Test

For robustness test, various watermarking attacks such as JPEG compression, filtering such as median and mean, histogram equalization, sharpening, Gaussian noise, salt & pepper noise, speckle noise and geometric attack such as cropping are applied on the watermarked medical images. The robustness is measured by calculating Normalized Correlation (NC). Figure 11 show the extracted watermark images for robustness test of proposed technique, along with their comparison with existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013) under various watermarking attacks.

Table 5 shows the NC value of extracted watermark images for proposed technique after application of watermark attacks on watermarked medical image and their comparison with existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013). It is to be noted that the proposed technique performs better than the other two techniques in resisting the attacks.

4.4. Computational Complexity

The computational complexity of watermarking technique is usually measured in terms of watermark image embedding and extraction processes time. The implementation of the proposed watermarking technique is done on the Laptop with 1.65 GHz dual core processor with 2 GB physical memory using MATLAB 2014a software. In this section, the computational time required for the watermark image embedding and extraction processes are calculated using host CT1 image and threshold T value

Figure 11. Extracted watermark images of proposed technique and existing techniques under various watermarking attacks

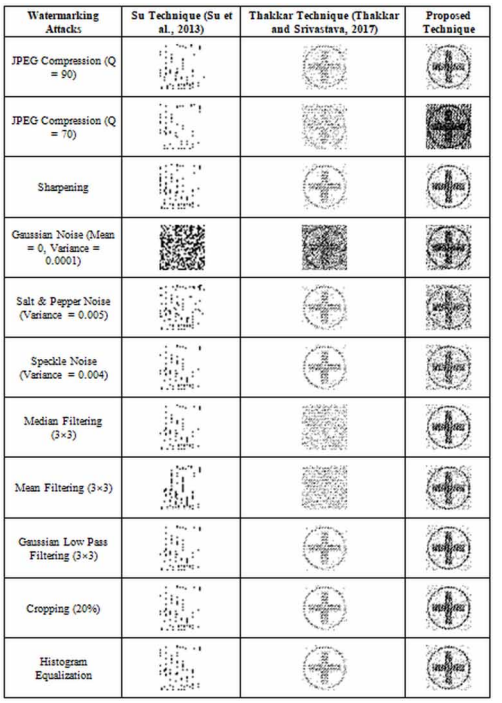


Table 5. Performance Comparison of proposed technique with existing techniques under various watermarking attacks

Watermarking Attacks	NC for Watermark Image		
	Su Technique (Su et al., 2013)	Thakkar Technique (Thakkar and Srivastava, 2017)	Proposed Technique
JPEG Compression (Q = 90)	0.0543	0.3434	0.9241
JPEG Compression (Q = 70)	0.0524	0.2015	0.5145
Sharpening	0.0737	0.4239	0.9500
Gaussian Noise (Mean = 0, Variance = 0.0001)	0.0097	0.2367	0.7801
Salt & Pepper Noise (Variance = 0.005)	0.0641	0.4319	0.8234
Speckle Noise (Variance = 0.004)	0.0564	0.4573	0.8975
Median Filtering (3×3)	0.0586	0.0491	0.9426
Mean Filtering (3×3)	0.0297	0.0068	0.9028
Gaussian Low Pass Filtering (3×3)	0.0543	0.4400	0.9394
Cropping (20%)	0.0585	0.4643	0.9447
Histogram Equalization	0.0256	0.4491	0.9379

Figure 12. Computational time (in seconds) of the proposed technique

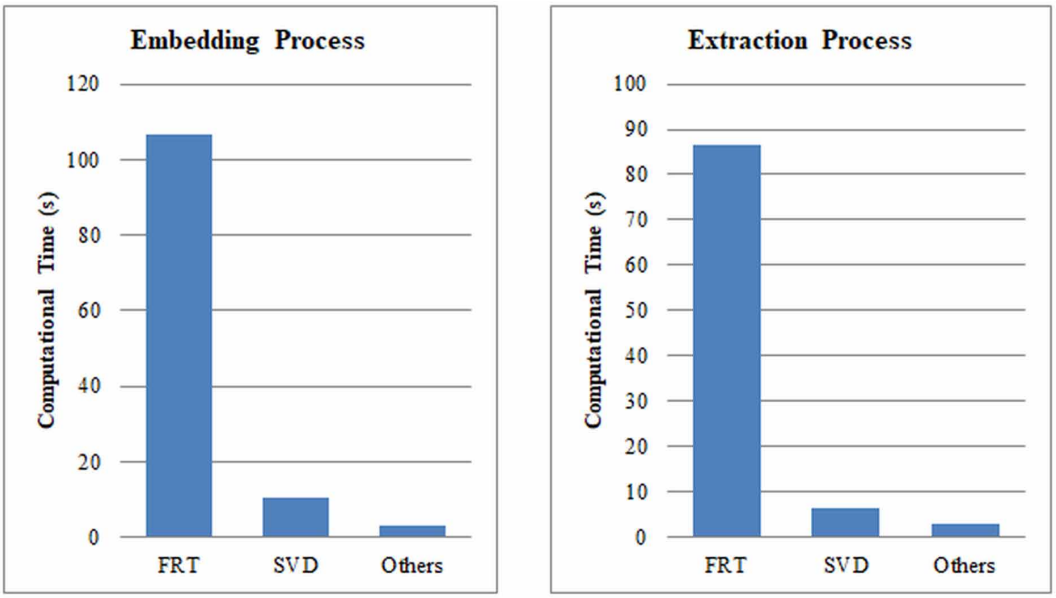


Table 6. Comparison of proposed technique with existing techniques

Parameters	Su Technique (Su et al., 2013)	Thakkar Technique (Thakkar and Srivastava, 2017)	Proposed Technique
No. of Transforms	1	2	2
Used Image Processing Transform	SVD	DWT + SVD	FRT + SVD
Watermark distribution	Whole image	Region of Interest (ROI) only	Whole image
Maximum PSNR (dB)	29.52	33.34	47.64
Maximum NC	0.3082	0.4615	0.8044

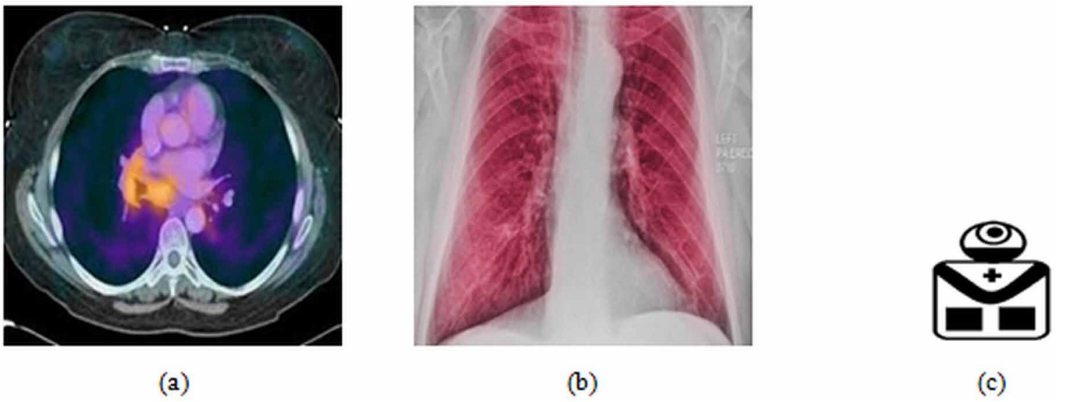
= 2. The total computational time for watermark embedding process is 120.478 s and watermark extraction process is 95.420 s, respectively. The computational times of different processes involved are plotted in Figure 12. It is to be noted that the steps of FRT and SVD in watermark embedding and watermark extraction process takes almost 85% and 10% of the whole computational time, respectively. Therefore, there is a scope to reduce the computational time in future using advanced algorithms and machines with high processing speed and high physical memory.

4.5. Comparison of Proposed Technique With Existing Techniques

The proposed technique is also compared with existing techniques by various features in Table 6.

The watermarking in the Thakkar technique (Thakkar and Srivastava, 2017) is performed in SVD-DWT domain, the Su technique (Su et al., 2013) is performed in SVD domain. The watermarking in proposed technique is performed in the SVD-FRT domain. The average PSNR value in the Su technique (Su et al., 2013) is 29.52 dB, Thakkar technique (Thakkar and Srivastava, 2017) is 33.34 dB, and in proposed technique is 47.64 dB, respectively. The average NC value in the Su technique (Su et al., 2013) is 0.3082, in the Thakkar technique (Thakkar and Srivastava, 2017) is 0.4615, and in

Figure 13. Test host color medical images (a) CT (b) X-ray and (c) watermark image



the proposed technique it is 0.8044. The average results indicated that performance of the proposed technique is better than existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013) in term of imperceptibility, robustness, and security. Further, the proposed technique distributes the watermark over the whole image, unlike Thakkar technique (Thakkar and Srivastava, 2017), where the watermark is confined to only region of interest portion (ROI) of the host medical image.

5. PERFORMANCE ANALYSIS OF PROPOSED TECHNIQUE FOR COLOR MEDICAL IMAGES

The performance analysis of the proposed technique for different grayscale medical images shows that it performs better than existing techniques (Thakkar and Srivastava, 2017; Su et al., 2013). In addition, the performance of this technique is tested for variety of color medical images such as CT (Pinterest color image library, 2017) and X-ray (Pinterest color image library, 2017) as shown in Figure 13. Here, a watermark image with sharp details is used.

The color medical image is decomposed into three channels R, G and B and then watermark data is inserting into the R channel of the image. The remaining procedure for watermark embedding and watermark extraction is same as in section 3. The watermark attacks are applied on watermarked color medical images before extraction of watermark data from it. This corrupted watermarked medical image is decomposed into three channels R, G and B, and the R channel is used for further extraction of watermark data. Figure 14 shows watermarked color CT images and extracted watermark images for different threshold (T) values.

The robustness of technique for color medical images is verified under various watermarking attacks such as JPEG compression, Gaussian noise, Salt & Pepper noise, mean filtering, histogram equalization and sharpening. The PSNR and NC values of color medical images for different threshold T values and without application of watermarking attacks are tabulated in Table 7.

The robustness results of Table 8 shows that the proposed technique performs equally well for the color medical images. The results also show that the imperceptibility of the proposed technique is better for color medical images compared to grayscale medical images.

6. CONCLUSION

This paper proposed an improved blind medical image watermarking technique using Finite Ridgelet Transform (FRT) and Singular Value Decomposition (SVD). In this technique, the watermark bits are

Figure 14. Watermarked color CT images and extracted watermark images for different threshold *T* values

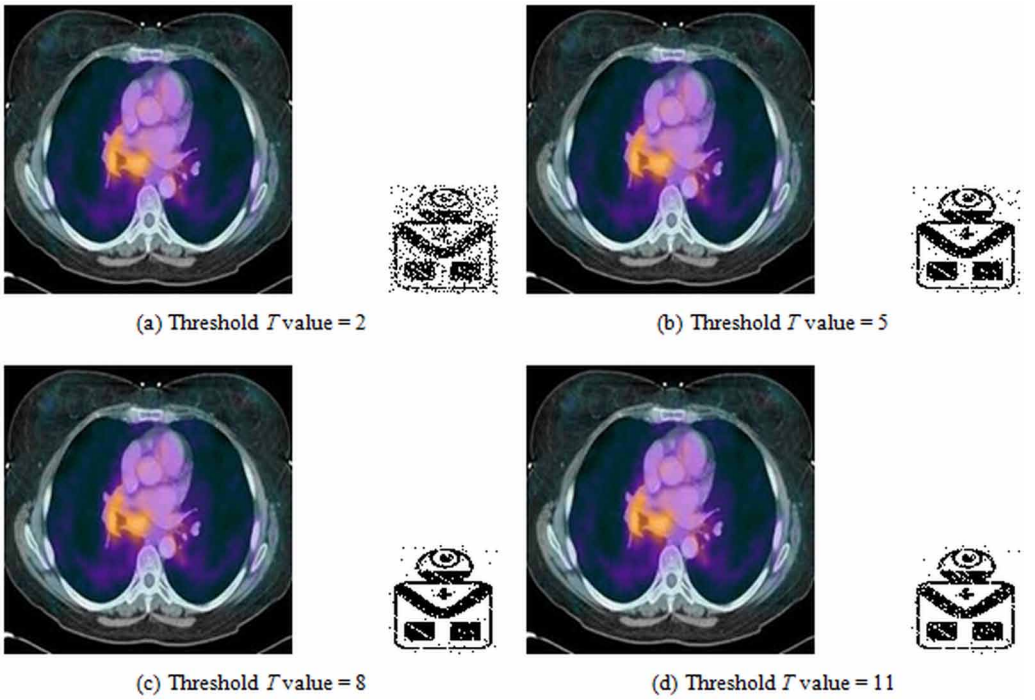


Table 7. PSNR (dB) and NC values of proposed technique for color medical images

Threshold *T* Value	CT		X-Ray	
	PSNR (dB)	NC	PSNR (dB)	NC
2	46.41	0.8679	52.60	0.8478
5	38.45	0.9615	44.64	0.9661
8	34.37	0.9834	40.56	0.9884
11	31.60	0.9990	37.79	0.9946

Table 8. Performance of proposed technique for color medical images under different watermarking attacks

Watermarking Attacks	NC for Watermark Image	
	CT	X-Ray
JPEG Compression (Q = 90)	0.7096	0.6294
JPEG Compression (Q = 70)	0.6549	0.6279
Gaussian Noise (Mean = 0, Variance = 0.0001)	0.6568	0.6013
Salt & Pepper Noise (Variance = 0.005)	0.6479	0.6144
Mean Filtering (3×3)	0.6668	0.5786
Sharpening	0.7088	0.6348
Histogram Equalization	0.6976	0.6263

embedded in the elements: U (1, 1) and value of U (2, 1) of U matrix, obtained after application of SVD on ridgelet coefficients of the medical image to be watermarked. Blind extraction of scrambled watermark bit is possible by comparing the values: U (1, 1) and U (2, 1) of U block of ridgelet coefficients at detector side. Arnold scrambling is used for enhancing the security of watermark information before embedding into host medical image. The proposed technique is tested for various medical images such as X-ray and CT scan and is compared with the performance of existing techniques. It is found that the proposed technique performs better in terms of imperceptibility, robustness, and security. The average PSNR value resulted is 47.64 dB, and NC value is 0.8044 for all types of tested medical images. Further, the proposed technique distributes the watermark over the whole image, unlike Thakkar Technique, where the watermark is confined to only part of the medical image. The limitation of this proposed technique is that it is applicable for CT scan, X-ray, and high contrast medical images. Further, this technique can embed only binary watermark images and is unable to embed Electronic Patient Record (EPR) data which is in text format. In future, the technique can be extended for insertion of large size of watermark data.

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