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Chaotic based secure watermarking approach for medical images

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Abstract
In this paper, a chaotic based secure medical image watermarking approach is proposed. The method is using non sub-sampled contourlet transform (NSCT), redundant discrete wavelet transform (RDWT) and singular value decomposition (SVD) to provide significant improvement in imperceptibility and robustness. Further, security of the approach is ensured by applying 2-D logistic map based chaotic encryption on watermarked medical image. In our approach, the cover image is initially divided into sub-images and NSCT is applied on the sub-image having maximum entropy. Subsequently, RDWT is applied to NSCT image and the singular vector of the RDWT coefficient is calculated. Similar procedure is followed for both watermark images. The singular value of both watermarks is embedded into the singular matrix of the cover. Experimental evaluation shows when the approach is subjected to attacks, using combination of NSCT, RDWT, SVD and chaotic encryption it makes the approach robust, imperceptible, secure and suitable for medical applications.

Keywords Image watermarking · NSCT · RDWT · SVD · Chaotic encryption · PSNR · NC · NPCR · UACI

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1 Introduction

Recently, health care professionals are using telemedicine applications to diagnose, assess and treat patients at remote/distance via electronic communications [27, 28]. In this application, medical images are exchanged between two health care professionals for better diagnosis purpose. However, transmission of medical images/EPR over open networks needs high degree of security [8, 27, 28]. The modified, altered or corrupted medical data can make wrong diagnoses and create serious health issues for any individual. In addition, medical identity theft is a growing concern and has contributed to large amount of e- fraud cases across the world [27]. Potential researchers have developed various methods for the authenticity of health related data and prevent the medical related identity theft (https://www.forbes.com/sites/forbestechcouncil/2017/12/15/the-real-threat-of-identity-theft-is-in-your-medical-records-not-credit-cards/#3221cf1a1b59) [13, 31, 35]. The digital watermarking provides one of the valuable tools for authenticity, confidentiality and integrity of medical data. In this tool, we embed useful digital information called a watermark into the cover media and it ensures the security of medical data. Further, the embedded watermark (s) information aims to provide owner identification, copyright protection, tamper detection and proofing of medical data. Currently, researchers are focusing towards the use of cryptographic methods with watermarking schemes enabling an optimal balance between security and robustness especially in case of telemedicine applications [6]. Research established that the spatial domain based techniques are less robust to attacks than transform based techniques [28, 31]. However, spatial domain based watermarking requires less processing time than the technique which embeds data in the transform domain. Recently, DWT is emerging as a more efficient transform domain technique in comparison to the others. However, shift variant and poor directional information are the major drawback associated with DWT. The shift variant drawback is recently avoided by using RDWT [7]. However, RDWT does not provide rich directional information. In [29], multiple features such as shift-invariant, multi-scale, and rich directional information of NSCT are introduced which make it suitable for many image processing applications. Further, the concept of multiple watermarking enhances the security, reduces need for storage and bandwidth during transmission. It also tackles the issues faced by health data management by embedding less robust watermark information at the lower decomposition level and more robust watermark at higher decomposition level [27].

In this paper, we propose a RDWT, SVD and chaotic encryption based secure medical image watermarking technique in NSCT domain. Singular value decomposition (SVD) [7] is computationally expensive when applied separately to medical images. So, the hybrid method (RDWT and SVD) is a good choice to compensate the problem and improve the performance of our method. The method further uses a logistic map chaotic encryption algorithm [37] for better security of the medical data.

The remaining of the paper is structured as follows: section 2 introduces various relevant techniques. Section 3 gives the importance of techniques used. Our method is introduced in section 4. The performance our method is highlighted in section 5. We summarize our work in section 6.

2 Related work

Brief outlines of some secure watermarking techniques using medical images are presented below:

In [23], the researcher developed a hybrid multiple watermarking techniques in transform domain. The method uses simple encryption technique to encrypt the text watermark for better

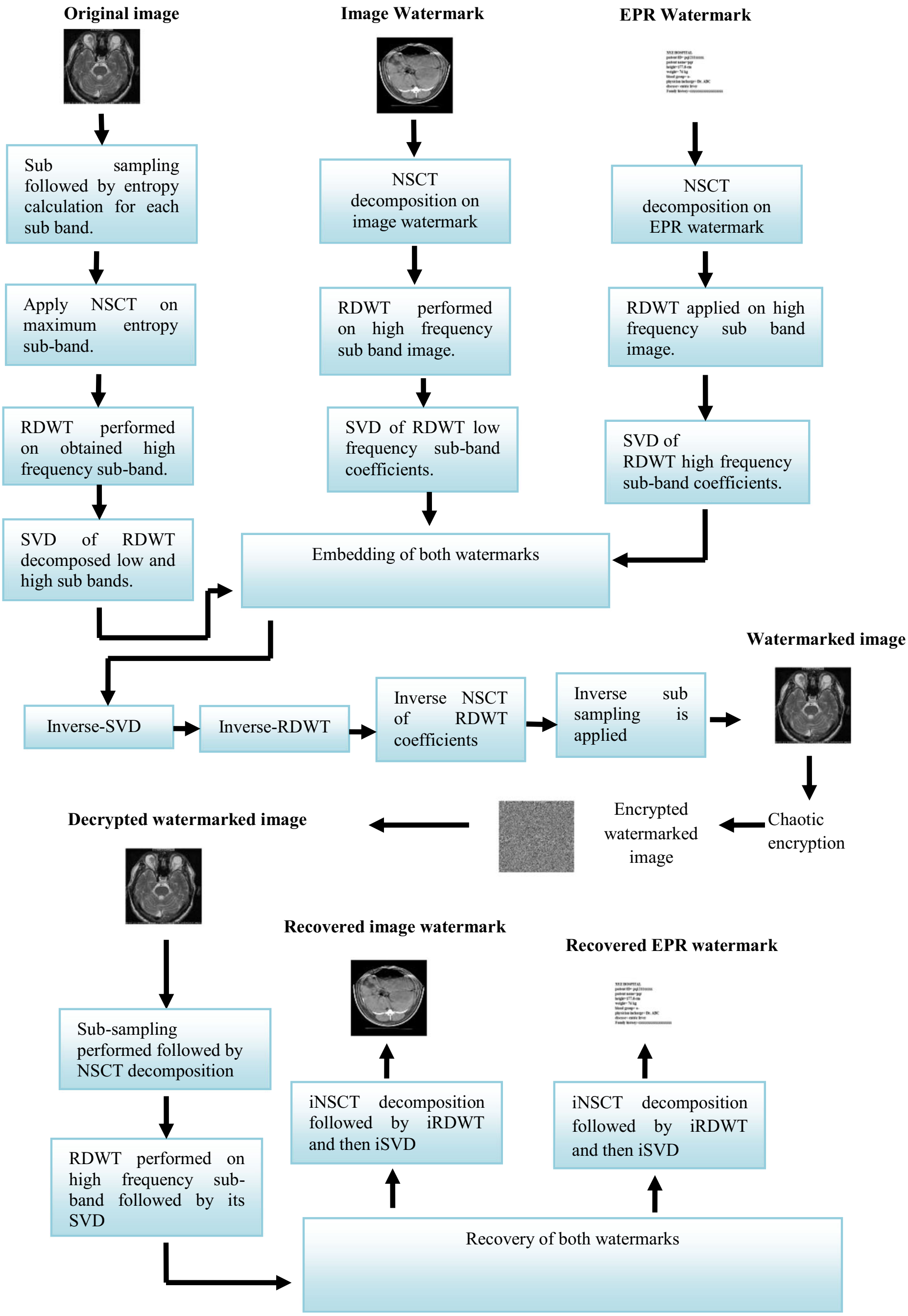


Fig. 1 Flow diagram of proposed watermark embedding and extraction procedure

security. Extensive evaluation of the scheme demonstrated its superior performance to similar techniques [21, 24, 26, 32]. An NSCT based watermarking approach in transform domain is introduced by Singh et al. [29]. The method uses combination of different techniques to make

Table 1 Performance measures at different gain and same size of watermarks

Gain factor	PSNR (in dB)	NC1 (256 × 256)	NC2 (256 × 256)	NPCR	UACI
0.01	39.0944	0.9966	0.9983	0.9960	0.3469
0.1	39.1402	0.9989	0.9983	0.9960	0.3469
0.5	39.3049	0.9984	0.9983	0.9960	0.3468
0.9	39.3969	0.9983	0.9983	0.9959	0.3467

watermarking approach robust and imperceptible and has superior performance to similar techniques [21, 24, 26, 30, 32]. A robust watermarking method is proposed in [38]. Subsequently the method embeds three watermarks in transform domain. The method uses various approaches to make the method efficient for medical applications. Experimental results showed improved robustness in comparison to Singh et al. as discussed in [26]. In [18], a reversible watermarking technique is developed for healthcare applications. The technique uses intermediate significant bit (ISB) for embedding two separate watermarks into the host image for content verification at receiver side. Further, chaos based encryption is used for better security. Lei et al. [15] presented an IWT based watermarking scheme. The selected sub-bands of the IWT cover image are utilized for embedding the fragile and robust watermarks. Further, artificial bee colony (ABC) algorithm was used to create an optimal balance between robustness, imperceptibility and embedding capacity of the watermarking system. Experiments demonstrated that the method is better to other approaches [3]. In [33], authors have developed a transform domain based robust and reversible watermarking method for securing medical related information. The method performs DWT on ROI section of the cover/host medical image and SVD is applied on the selected DWT sub-band of the ROI of host image. The method uses selected SVD block (‘U’ matrix) to embed watermark data. In addition to this, error correction code is used to encode the EPR watermark data and embedded into the RONI region of the host image. Performance evaluation of the proposed method showed its superiority in comparison to others [17, 25].

For Tele-ophthalmology application, Pandey et al. [16] described a region based watermarking scheme. The considered watermarks are embedded into the non – region of interest (NROI) part of the cover image.

The EPR watermark is modified with ROI (SHA-512 generated hash) section before being embedded into the RONI section of the cover. Experimental evaluation of the proposed method gives better performance than Singh et al. scheme [25] and is secure and robust against various attacks including Checkmark attacks. Anusudha et al. [4] proposed a joint encryption and watermarking technique for e- health applications in which two separate watermarks are embedded into particular DWT sub-bands of original/host medical image. The proposed method is tested for different attacks. The method has shown improvement in performance as compared to other schemes [1, 39]. Al-Haj et al. [2] presented a joint cryptographic watermarking method using DWT-SVD based transform domain techniques.

Table 2 Performance measures at different gain and size of the watermarks

Gain factor	PSNR (in dB)	NC (256 × 256)	NC (128 × 128)	NPCR	UACI
0.01	37.0894	0.9959	0.9211	0.9958	0.3462
0.1	37.0596	0.9989	0.9624	0.9960	0.3471
0.5	36.8035	0.9983	0.9625	0.9958	0.3466
0.9	36.3747	0.9982	0.9623	0.9960	0.3475

Table 3 Performance measures for different medical cover images

Image modality	PSNR (in dB)	NC1 (256 × 256)	NC2 (128 × 128)	NPCR	UACI
Hand X-ray	38.6088	0.9988	0.9623	0.9963	0.4025
Ultrasound	26.9343	0.9990	0.9551	0.9958	0.4126
Brain MRI	37.0596	0.9989	0.9624	0.9960	0.3471
Breast MRI	36.6541	0.9989	0.9625	0.9962	0.3502
PET-scan	29.4585	0.9991	0.9632	0.9960	0.4461
SPECT	32.4592	0.9992	0.9633	0.9959	0.4262
Kidney stones	32.7698	0.9993	0.9629	0.9961	0.3538
Abdomen CT	32.5664	0.9989	0.9624	0.9962	0.4126
Chest CT	32.3148	0.9993	0.9546	0.9962	0.3220

The ROI and RONI sections concerned with all four sub-bands are defined before applying any transformations. The cover image is decomposed by applying DWT and SVD on selected sub- bands. The embedding of the watermark data, which is in the form of logo, EPR and hash is done into the greater singular value of the RONI section of chosen DWT sub-bands of cover. Experimental analysis for imperceptibility, tamper localization and robustness proved that the method stands suitable for telemedicine applications. Elhoseny et al. [11] proposed a secure hybrid approach which combines 1 and 2 level two dimensional DWT technique with encryption mechanism based on RSA and AES. Performance analysis in terms of PSNR, MSE, SSIM, BER, NC and structural content (SC) showed its superiority in comparison to similar method [5]. Shehab et al. [22] presented a fragile watermarking method based on SVD which is recoverable and provides tamper localization. Initially, the cover image is decomposed into 4× 4 blocks after which SVD is applied. Further, Arnold transform has been applied to determine the appropriate embedding location. Experimental evaluation of the proposed method proves its enhanced performance as compared to other state-of-the-art techniques [9, 10, 19, 20]. The authors in [34] proposed a joint watermarking and cryptographic algorithm based on DWT-DCT -SVD and chaotic encryption. From the experimental results it is evident that the proposed algorithm is secure and is found to be robust against various attacks. Further, the proposed method showed improved performance when compared to similar existing methods [14, 25].

3 Major contributions of the work

This paper attempts to offer a fusion of transform domain watermarking techniques coupled with chaotic based encryption. The objective of considered techniques in our proposed method as follows:

Table 4 Performance measures for non-medical images

Image modality	PSNR (in dB)	NC1 (256 × 256)	NC2 (128 × 128)	NPCR	UACI
Zelda	42.0123	0.9988	0.9632	0.9958	0.2971
Lena	37.0323	0.9990	0.9632	0.9961	0.2853
Barbara	38.4987	0.9987	0.9631	0.9959	0.4206
Cell	54.4978	0.9982	0.9626	0.99603	0.2555
Coins	41.7215	0.9988	0.9632	0.9962	0.3076

Table 5 Performance measures for different wavelet filters

Wavelet filter	PSNR (in dB)	NC (256 × 256)	NC (128 × 128)	NPCR	UACI
Coif2	36.4631	0.9985	0.9604	0.9959	0.3469
db2	37.7835	0.9985	0.9574	0.9960	0.3472
db10	36.5857	0.9983	0.9593	0.9960	0.3472
Bior1.3	37.0593	0.9985	0.9637	0.9959	0.3469
Bior6.8	37.4758	0.9980	0.9618	0.9963	0.3475

- The Shift-invariant, multi-scale, and rich directional information of NSCT make it suitable for many image processing applications [29].
- The shift variant drawback of DWT is recently avoided by using RDWT [29].
- The concept of SVD in image processing applications finds its usability due to its particular mathematical properties of the singular values which provides excellent consistency. However, SVD [27] is computationally expensive when it is applied separately to images. So, the hybrid method (RDWT and SVD) is a good choice to compensate the problem and improve the robustness of our proposed method.
- Chaotic encryption [37] is using for securing medical images, sensitive patient data and digital information. The pseudorandom nature which governs the concept of chaotic encryption is utilized for achieving better security when used together with watermarking techniques [12]. The NPCR and UACI are used to measure the security performance of the encryption technique.

4 Design of proposed method

The proposed algorithm uses a combination of NSCT, RDWT and SVD for watermark embedding and extraction process. Using a combination of these two transforms helps in obtaining recovered watermarked images of better quality. Initially the cover image is decomposed using the sub sampling method to derive the sub-sampled components. Entropy values of these components are determined and NSCT is applied on maximum entropy components. RDWT is applied to the high frequency sub band of NSCT

Table 6 Robustness test for different attacks

Attack	Noise density	NC 1	NC 2
Salt and pepper noise	0.01	0.9528	0.9633
	0.08	0.9610	0.9586
Gaussian noise	0.01	0.9539	0.9625
	0.5	0.9666	0.9324
JPEG compression	Q = 10	0.9986	0.9633
	Q = 50	0.9666	0.9324
	Q = 90	0.9988	0.9632
Rotation	2°	0.9986	0.9633
Gaussian low-pass filter	Var =0.4	0.9989	0.9624
	Var = 0.6	0.9989	0.9624
Image scaling	×1.1	0.9986	0.9632
Median filter	[2 2]	0.9826	0.9318
Histogram equalization		0.9980	0.9626

Table 7 Robustness comparison of our method with 'Singh' approach [23]

Attack	Noise density	Singh [23]	NC values by proposed method
Gaussian noise	mean = 0,Var-0.5	0.6569	0.9329
Gaussian noise	mean = 0,Var-0.01	0.9604	0.9626
Salt & pepper noise	0.08	0.8859	0.9558
Histogram equalization		0.931	0.9632

decomposed image. Further, SVD is applied to the selected sub-bands of RDWT transformed components. Similarly, both watermark images are transformed using NSCT decomposition followed by RDWT and SVD. The process of watermark embedding is done by using the modified SVD coefficients with help of gain factor 'α'. The method further encrypts the watermarked image through logistic map chaotic encryption algorithm for better security of the medical data [37]. The watermark recovery process is done by performing NSCT-RDWT and SVD decomposition on the decrypted watermarked image to obtain the recovered watermark components from modified SVD coefficients. Further, inverse of NSCT-RDWT and SVD is applied on the recovered components to finally obtain the recovered watermark images separately. Flow diagram of our proposed scheme is presented in Fig. 1.

5 Experimental results

An experimental result of the proposed algorithm is analysed using cover medical and non-medical images of size 512 × 512. Further, two watermarks of size 256 × 256 (thorax image) and 128 × 128 (electronic patient record (EPR)) are used for experimental purpose. The EPR watermark contains the doctor and patient information however second watermark gives the patient medical image. We have embedded more robust watermark (EPR watermark) at higher decomposition level and less robust watermark (patient medical image) at lower decomposition level.

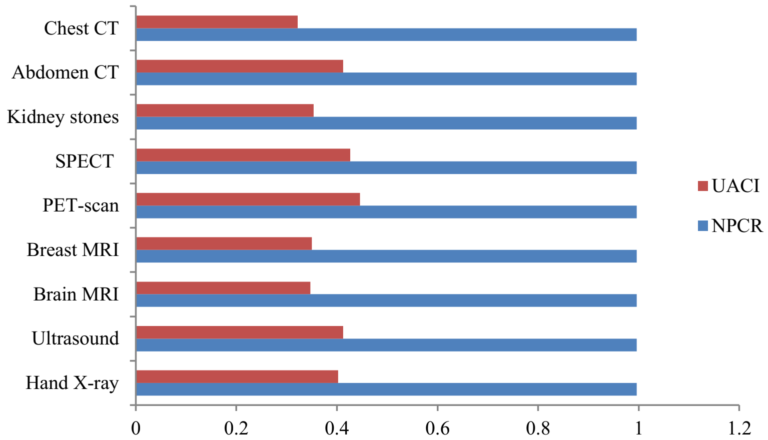


Fig. 2 NPCR and UACI performance for various medical images

Table 8 Robustness (determined by NC) comparison of our method with Zear et al. [38]

Attack	Noise density	Zear et al. [38]	Our method
JPEG compression	Quality factor = 10	0.3120	0.9986
Salt and pepper noise	0.01	0.7747	0.9633
Gaussian noise	Mean = 0, Var = 0.001	0.9466	0.9989
Speckle noise	Var =0.01, 0.02 and 0.005	0.9286, 0.8673 and 0.9886	0.9988, 0.9990 and 0.9988
Rotation	2°	0.4442	0.9986

The proposed algorithm is implemented using MATLAB R2013a on a 64-bit PC having Core-i5 7th generation processor and 8 GB RAM. Extensive analysis is carried using both general images and gray level medical images. Peak-signal-to-noise ratio (PSNR) [27], normalized correlation (NC) [27], number of changing pixel rate (NPCR) and unified averaged changed intensity (UACI) are used to measure the performance of our approach. The detail discussion about UACI and NPCR is presented in [37]. Normalized correlation between original thorax watermark image and recovered thorax image is represented by 'NC1' and original EPR watermark and recovered EPR watermark is denoted by 'NC2'. The brief performance analysis of the work is presented in Tables 1, 2, 3, 4, 5, 6, and 7. Performance of our method is estimated for same sizes of watermarks (256 × 256) at varying gain are presented in Table 1. In this table we found the best value of NC1, NC2 and PSNR are 0.9989, 0.9983 and 39.3969 dB, respectively. The NPCR values obtained for different gain factor values are found to be better than the acceptable values [36]. However, UACI values achieved are found to be more than 33.93% which is approximately near to the acceptable value [36]. Table 2 shows the performance of our method (determined by PSNR, NC, NPCR and UACI) for different size watermarks (256 × 256 and 128 × 128) and gain values. Here best PSNR = 36.8035 dB (gain factor = 0.5), NC 1 = 0.9989 (gain = 0.1) and NC2 = 0.9625 at gain = 0.5. Table 3 shows the performance of our method for nine different cover medical images. It is noticed that the best PSNR is obtained for 'hand X- ray' image. Further, robustness test for kidney stones, chest CT and SPECT images are superior to other medical cover images. Figure 2

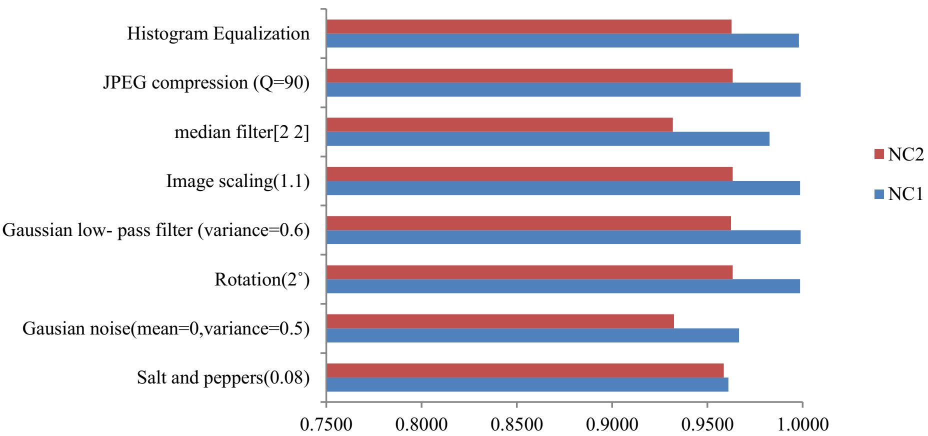


Fig. 3 Robustness test under attacks

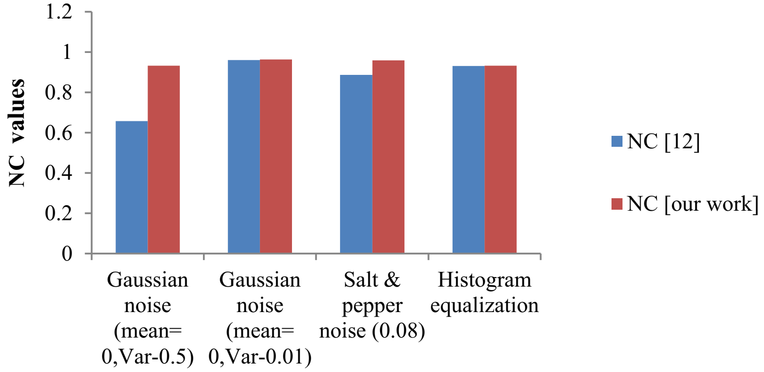


Fig. 4 Comparison of NC values with Singh et al. [23]

depicts NPCR and UACI values obtained for different medical image modalities. Table 4 shows the performance of our method for 'non- medical' cover images. Form Table 4, the highest and lowest PSNR value is 54.4978 dB and 37.0323 dB obtained for cover image 'cell' and 'Lena' respectively. However, NCs values are always greater than 0.9 in all cases. Table 5 shows the performance of proposed method for different wavelet filters. The best PSNR is obtained for 'db2' filter. However, NCs values are always greater than 0.9 for the considered filters. Table 6 shows the robustness test of our method for different attacks at gain = 0.1. We noticed that the NCs values are always greater than 0.9 under considered attacks. Tables 7 and 8 clearly indicate the effectiveness of superiority of our method to other approaches [23, 38]. The robustness test of our method under different attacks is shown in Fig. 3. Figures 4, and 5 show the comparative analysis of the proposed work with similar techniques [23, 38]. Further, few attacked watermarked images and recovered watermark images with their respective NC values are depicted in Table 9.

All experimental discussion clearly shows our approach is robust, imperceptible, secure and efficient for healthcare applications.

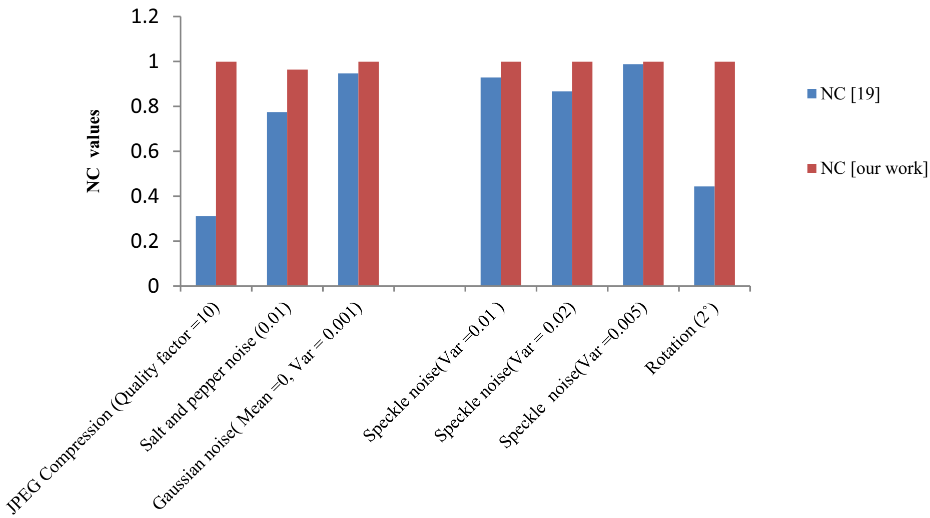
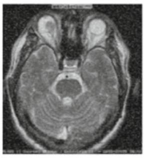
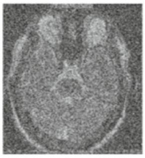
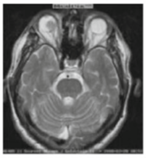
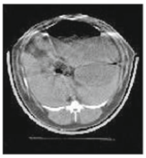
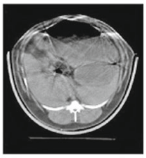


Fig. 5 Comparison of NC values with Zear et al. [38]

Table 9 Attacked watermarked and recovered watermark image under different attacks

Attacks	Attacked image	Obtained NC1 values	Obtained NC2 values	Recovered watermark image 1	Recovered watermark image 2
Salt and pepper noise (density = 0.08)		0.9610	0.9586		
Gaussian noise (density = 0.5)		0.9666	0.9324		
JPEG Compression (Q = 90)		0.9988	0.9632		
Rotation 2°		0.9986	0.9633		

6 Conclusion

This paper presented a joint cryptographic and watermarking method for medical images based on NSCT- RDWT and SVD. Further, the security aspect of the proposed method is enhanced using chaotic based encryption approach. Experimental evaluation shows when the approach is subjected to attacks, using combination of NSCT, RDWT, SVD and chaotic encryption it makes the approach robust, imperceptible, secure and suitable for medical applications. The proposed technique achieved maximum PSNR, NC, NPCR and UACI value up to 54.49 dB, 0.9993, 0.99, and 0.34 (nearly), respectively. When attacks are considered, our method also has superior NC values compared to other schemes. In future, the performance of our approach can be improved and extended for other multimedia applications such video and audio watermarking.

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