A Watermarking Algorithm for Multiple Watermarks Protection Using RDWT-SVD and Compressive Sensing

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In this paper, a watermarking algorithm is proposed and analyzed using RDWT-SVD and Compressive Sensing for multiple watermarks protection. In this algorithm, the multiple watermarks are inserted into single host medium. Here three watermarks are converted into its CS measurements using compressive sensing procedure before embedding into host medium. The CS measurements of watermarks are generated using discrete cosine transform (DCT) and normal distribution matrix. The singular value of these CS measurements of multiple watermarks is inserted into the singular value of approximation wavelet coefficients of R channel, G channel and B channel of color host image to get watermarked color image. The experimental results show that this proposed algorithm is equally worked for all types of watermarks. This proposed algorithm also provides robustness against various watermarking attacks and performed better than existed algorithms in the literature.

Povzetek: Opisani so algoritmi za zaščito vodotiska.

1 Introduction

Nowadays, research on digital watermarking is not a new phenomenon. Because of various digital watermarking algorithms are discussed and proposed by various researchers in last fifteen years [1–22]. These algorithms are designed for various types of information such as digital image, digital video, digital audio, and text. The digital watermarking algorithms can be classified into various categories based on processing domain, type of host medium, type of watermark information and type of application. The digital watermarking algorithms based on processing domain are divided into the spatial domain, transform domain and hybrid domain. In spatial domain watermarking, pixel information of host medium is modified according to watermark information. In transform domain watermarking, frequency coefficients of host medium are modified according to watermark information. The signal processing transforms such as fast Fourier transform (FFT), discrete cosine transform (DCT), discrete wavelet transform (DWT), redundant discrete wavelet transform (RDWT) and singular value decomposition (SVD) are used in transform domain based watermarking algorithms. In hybrid domain watermarking, hybrid coefficients (which is a combination of two or more transform coefficients) of host medium is modified according to watermark information. The limitation of spatial domain watermarking algorithms is that there are not secure against any manipulations [1, 21]. The transform domain watermarking algorithms have overcome the limitation of spatial domain watermarking algorithms but have less payload capacity [21]. The hybrid domain watermarking algorithms are performed better than spatial and transform domain algorithms.

The digital watermarking algorithms based on the type of host medium are divided into image watermarking, video watermarking, audio watermarking and text watermarking [21]. The digital watermarking algorithms based on the type of watermark information are divided into image watermarking and biometric watermarking [21, 23]. In image watermarking, standard image or image of the logo, the text is taken as watermark information and inserted into host medium. In biometric watermarking, biometric such as fingerprint, face, iris, speech, and signature is taken as watermark information and inserted into host medium. The digital watermarking algorithms based on the type of application are divided into robust watermarking and fragile watermarking. The robust watermarking is providing protection against any manipulation and used for copyright protection of information [2-22]. The fragile watermarking is not providing protection but providing authentication against any manipulation and used for copyright authentication of information [1, 23-24].

The watermarking algorithms mentioned in [1-24] are used single watermark information and inserted into host medium. Therefore, the strong need of watermarking algorithm is required which can be inserted multiple watermarks information into host medium. So many researchers are discussed and proposed various watermarking algorithms which can be inserted multiple watermarks information. This type watermarking algorithm is called as multiple watermarking algorithms [25]. The multiple watermarking algorithms are divided into three types such as composite, successive and segmented [25]. The composite based multiple watermarking algorithms are inserted combined multiple watermarks as a single watermark and then inserted into host medium. The successive based multiple watermarking algorithms are inserted one by one watermark into host medium. The segmented based multiple watermarking algorithms are inserted multiple watermarks into the specific slot of host medium.

Recently, there are a lot of new watermarking algorithms are proposed by researchers for the security of various multimedia data. S. Borra and her research team proposed a lossless watermarking technique based on visual cryptography and central limit theorem for the protection of high-resolution images and sensitive images [26, 27]. Surekha Borra has also proposed a watermarking technique based on visual secret sharing for image protection [28]. There are also various new watermarking algorithms are proposed by N. Dey and his research team for the security of various biometric data such as fingerprint, retina, ECG signal and EEG signal [29-32]. These algorithms are designed using various transforms such as DCT, DWT, and SVD. These algorithms are used various approaches such as spread spectrum, an edge detection algorithm for achieved better results and security to data. In 2016, researchers have introduced a watermarking algorithm for 3D images protection [33].

In this paper, a watermarking algorithm is proposed for the security of multiple watermarks using stationary wavelet transformation (SWT), signature value decomposition (SVD) and compressive sensing (CS) theory. The SWT is also known as redundant discrete wavelet transform (RDWT). This algorithm provides protection to multiple watermarks against various watermarking attacks. This algorithm can be used for security of multiple watermarks transferred over the non-secure communication channel. The CS theory provides security to watermark data before embedding into host medium. This step is introduced one additional security layer in conventional watermarking approach. This algorithm can be used for security of biometric data in the multimodal biometric system. Using this algorithm, a user can transfer any important multimedia data or biometric data over a non-secure channel or between two modules of the biometric system. This algorithm can provide copyright protection to multimedia data because multiple watermarks can be embedded into the host. Because imposter can not generate secure watermark data without information of orthogonal matrices U, V and embedding factor. U, V and embedding factor are used as a secret key in this algorithm.

The rest of paper is organized as follows: in section 2, related work to proposed algorithm is given. In section 3, mathematics and information on redundant discrete wavelet transform (RDWT); Singular Value Decomposition and CS theory are presented. Section 4 gives information on the implementation of proposed algorithm with multiple watermark insertion. The result and discussion for robustness and performance of proposed algorithm for different watermarks information against various watermarking attacks are given in section 5. Finally, the conclusion is given in section 6.

2 Related work

The review on watermarking algorithms mentioned in [25, 34–40] is related to proposed watermarking algorithm. Authors in [25] proposed a watermarking algorithm based on DWT and DCT for multiple biometric watermarks insertion. In this algorithm, first face information is inserted into host image to get face watermarked image. Then speech information is inserted into face watermarked image to get face-speech watermarked image. Finally, signature information is inserted visibly on DCT coefficients of face-speech watermarked image to generate multiple watermarks based watermarked image.

Authors in [34] proposed a watermarking algorithm based on visual cryptography for multiple watermarks insertion. In this algorithm, three watermarks information is inserted into Y component of the color image. Authors in [35] proposed a watermarking algorithm based on SWT and spread spectrum for EMG signal protection. Authors in [36] proposed a watermarking algorithm based on DWT for two watermarks insertion. In this algorithm, two watermarks information is inserted into LL subband and HH subband of host image to get watermarked image. This algorithm is robust against all type watermarking attacks.

Authors in [37] proposed a watermarking algorithm based on RDWT for biometric watermarks. In this algorithm, speech watermark information is divided into two portions and then inserted into wavelet coefficients of red channel and blue channel of the color face image. This algorithm provides robustness against watermarking attacks. Authors in [38] proposed correlation based and spread spectrum based watermarking algorithms for multiple watermarks insertion. In this algorithm, first watermark information is inserted into host image to get the first watermarked image. Then second watermark information is inserted into first watermarked image to generate multiple watermarks based watermarked image. These algorithms are spatial domain algorithms because here pixel information of host image is modified according to multiple watermarks.

Authors in [39] proposed RDWT and independent component analysis (ICA) based watermarking algorithm for multiple logo insertions. In this algorithm, multiple watermark logos are inserted into LH and HL subbands of the host image. This algorithm provides robustness against watermarking attacks. Authors in [40] proposed DWT and CS theory based watermarking algorithm for multiple biometric watermarks insertion. In this algorithm, CS measurements of multiple biometric watermarks are inserted into HH subband of various level of host biometric image. The payload capacity of watermarking algorithms mentioned in [34-40] is up to 50%.

After discussion on reviewed papers, it is cleared that most existed algorithms are based on successive based multiple watermarking with having less payload capacity. Also, the most of the existed algorithms are used grayscale host image for multiple watermarks insertion. These existed algorithms are also provided copyright protection to multiple watermarks but applied on one type of watermark information either image or biometrics. Thus, in this paper, a hybrid watermarking algorithm is proposed which focuses on high payload capacity. The motivation of the present work arises from developing a watermarking algorithm which inserted multiple watermarks information. In this paper, an algorithm is proposed which embeds multiple watermarks information in the red channel, green channel and blue channel of color host medium. The color host image is decomposed using redundant discrete wavelet transform (RDWT) and singular value decomposition (SVD). We have borrowed the idea from [41] with significant improvements in implementation and results. The work also goes a step further wherein multiple watermarks inserted and combined with compressive sensing (CS) theory [42-43].

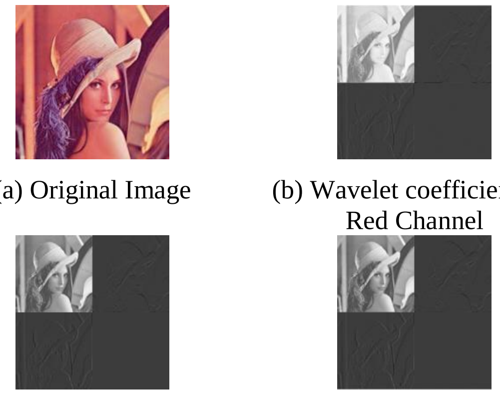
In this proposed algorithm, singular value of approximation wavelet subband of color host image is modified according to the singular value of CS measurements of multiple watermarks. This proposed algorithm offers good security and high payload capacity. In this algorithm, CS theory is applied to DCT coefficients of multiple watermarks information which are inserted into the color host image. In this proposed algorithm, Gaussian measurement matrix A is applied to the DCT coefficients of watermark image to get CS measurements of watermark image. The proposed algorithm is analyzed using various color host images and multiple watermarks for different gain factors. The orthogonal matching pursuit (OMP) [44] algorithm is used for extraction of watermark image from extracted CS measurements at detector side. This algorithm is selected because it has better computational time and easy to implemented.

3 Preliminaries

3.1 Redundant Discrete Wavelet Transform (RDWT)

The most common transform such as discrete wavelet transform is used for watermarking. But DWT has limitation such that downsampling of its subbands [39, 41]. This is cause payload capacity of watermarking algorithms. The DWT is also shift variance which may cause a problem in the extraction of watermark information. So overcome these limitations of DWT in watermarking, researchers are introduced redundant discrete wavelet transform (RDWT) for watermarking. The RDWT provides shift invariance which is better for extraction of watermark information at detector side. The RDWT is eliminated downsampling and the upsampling process of discrete wavelet transform. This transform provides more robust process than DWT. When RDWT is applied on any color image which decomposed the image into various coefficients are shown in Figure 1.

The different between discrete wavelet transform (DWT) and redundant discrete wavelet transform (RDWT) is shown in Figure 2 [39, 41].



(a) Original Image (b) Wavelet coefficients of Red Channel

(c) Wavelet coefficients of Green Channel (d) Wavelet coefficients of Blue Channel

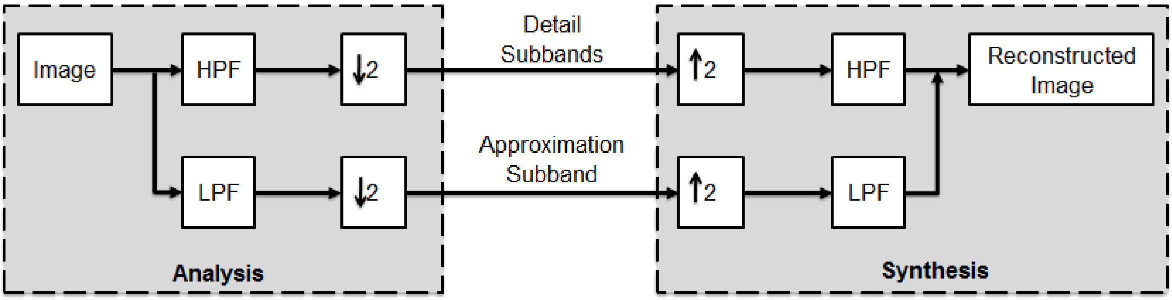
Figure 1: Wavelet Coefficients of RDWT for Color Image.

3.2 Singular Value Decomposition (SVD)

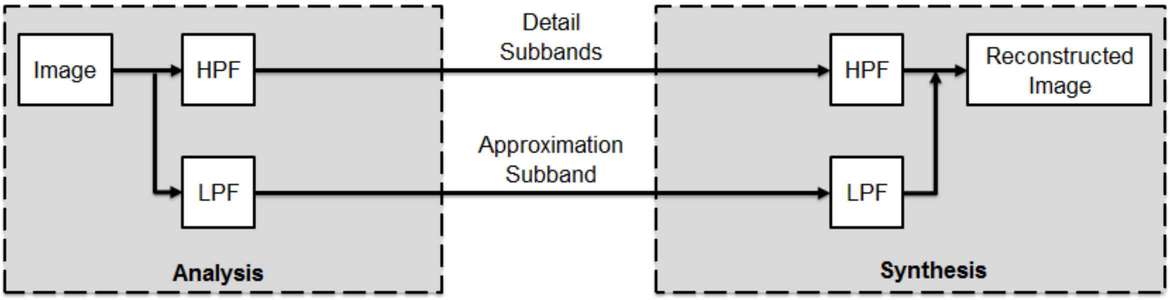
The singular value decomposition is a linear algebra tool which decomposes the image into three different matrices such as singular value matrix, two orthogonal matrices such as U matrix and V matrix. The singular value matrix has non-negative values and diagonally place in the matrix. The singular value has sparsity and stable property which is suitable for watermarking and compression sensing. This value is less effect on human visualization capacity when it is modified. When SVD is applied on any image is shown in Figure 3.

3.3 Compressive Sensing (CS) theory

An image f can become sparse image when only a few non-zero elements are presented in the image. The image f can be converted into a sparse image by applying image



(a)



(b)

Figure 2: (a) DWT Analysis and Synthesis for Image (b) RDWT analysis and Synthesis for Image.

transform basis matrix. The image has x non-zero coefficients (sparse coefficients) are represented as

$$x = \Psi(f) \tag{1}$$

where x is the sparse coefficients, Ψ is the transform basis matrix.

The CS measurements of image using compressive sensing represented by using following equation [42, 43]

$$y = A \times x \tag{2}$$

Where y is the sparse measurements, A is known as measurement matrix.

To reconstruction of an image from CS measurements, various CS recovery algorithms are available in the literature [42-45]. A greedy algorithm such as orthogonal matching pursuit (OMP) is used which is introduced and designed by Tropp et al. [44]. The more detail on OMP algorithm is given in next subsection. It is used in this paper for the extraction of sparse coefficients from CS measurements. It can be mathematically explained using below equation:

$$x^* = OMP(y, A) \tag{3}$$

Where x^* is extracted sparse coefficients which are extracted from the CS measurements y.

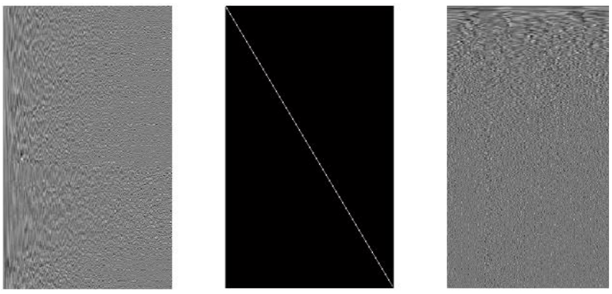


Figure 3: SVD Matrices of Image: U Matrix (left), S Matrix (middle), V Matrix (right).

3.4 Orthogonal Matching Pursuit (OMP) algorithm

The Orthogonal Matching pursuit (OMP) algorithm is introduced and designed by J. Tropp and A. Gilbert in 2007 [44]. This algorithm is a greedy algorithm which is used for extraction of sparse coefficients from the CS measurements. The OMP algorithm is defined by three basic steps such as matching, orthogonal projection, and residual updating. The output of OMP algorithm is one non-zero sparse coefficient in each iteration. The OMP algorithm extracted sparse coefficients x from $y=Ax$. The mathematical steps for OMP algorithm are described in below steps:

- **Input:** CS measurements $\boldsymbol{y}$, Measurement matrix $\boldsymbol{A}$
- **Initialization:** index $\boldsymbol{I} = \boldsymbol{A}$, residual $\boldsymbol{r} = \boldsymbol{y}$, sparse representation $\boldsymbol{\theta} = \boldsymbol{0} \in \boldsymbol{Rm}$.
- **Step 1:** Initialize the residual $r_0 = y$ and initialized the set of selected variable $x(c_0) = \phi$. Let iteration counter i = 1.

$$\max_t \left| x_t' r_{i-1} \right| \tag{4}$$

- **Step 2:** Find the variable x_t that solves the maximization problem below using equation (4) and add the variable x_{ti} to the set of selected variables. Update C_i using equation (5).

$$C_i = C_{i-1} \cup \{t_i\} \quad (5)$$

- **Step 3:** Let P_i which is given below equation (6) denote the projection onto the linear space spanned by the elements of $x(c_i)$. Then update residual r using equation (7).

$$P_i = x(C_i)(x(C_i)' x(C_i))^{-1} x(C_i)' \quad (6)$$

$$r_i = (I - P_i) y \quad (7)$$

- **Step 4:** It the stopping condition is achieved, stop the algorithm. Otherwise, set $i = i + 1$ and return to step 2.
- **Output:** Sparse Coefficients ***x*.**

The solution of equation 6 is getting by least square optimization method. The value of projection *Pi* is taken as extracted sparse coefficients *x*. The value of extracted sparse coefficients depends on linear projection between CS measurements vector and measurement matrix-vector. When both vectors have equal value then the output is zero because the projection is zero. So every time, the output of OMP algorithm is non-zero coefficients.

4 Watermarking algorithm using RDWT-SVD and CS theory

Today's world, the data size of multimedia is also increasing day by day. Also, the existed watermarking techniques are embedded multiple watermarks information in host image but the size of watermark information is few bits or less than the size of the host image. Thus, the new watermarking algorithm should have more secure and higher payload capacity. So, in the proposed algorithm CS is used for providing security to multiple watermarks information before embedding. In the proposed algorithm, redundant DWT is applied on RGB channel of color host image to get wavelet coefficients of RGB channel of the color host image. Then SVD is applied on these coefficients to get the singular value of RGB channel of the color host image. Then the singular value of approximation subbands is chosen for CS measurements embedding because of these coefficients are less effect by watermarking attacks. The CS measurements of multiple watermarks information are generated using DCT and Gaussian measurement matrix. In this section, the multiple watermark embedding procedure and extraction procedure of proposed algorithm are described.

4.1 Multiple watermark embedding procedure

The multiple watermark images are transformed into the sparse domain using discrete cosine transform (DCT).

- Take color host image *IH* and compute the size of the host image. Then color image decomposed into R channel, G channel and B channel.

The CS measurements *y* of watermark images is generated using compressive sensing with Gaussian measurement matrix. The singular value of CS measurements *y* of watermark images is embedded into the singular value of LL subband of RGB channel of the color host image. Figure 4 shows the framework for the proposed embedding procedure and the mathematical steps for multiple watermark embedding are given below.

- Take multiple watermarks w_1, w_2, w_3 and compute the size of watermarks. Apply DCT on watermark 1, watermark 2 and watermark 3 to get DCT coefficients of watermark 1, watermark 2 and watermark 3, respectively.

$$D_1 = dct(w_1)$$
$$D_2 = dct(w_2) \quad (8)$$
$$D_3 = dct(w_3)$$

In above equation, w_1, w_2, *and* w_3 are watermark 1, watermark 2 and watermark 3, respectively; D_1, D_2, *and* D_3 are DCT coefficients of watermark 1, watermark 2 and watermark 3, respectively.

- Then generate CS measurements of watermark 1, watermark 2 and watermark 3 using Compressive sensing procedure. The Gaussian measurement matrix is generated using zero mean and one variance.

$$y_1 = A \times D_1$$
$$y_2 = A \times D_2 \quad (9)$$
$$y_3 = A \times D_3$$

In above equation, y_1, y_2, *and* y_3 are CS measurements of watermark 1, watermark 2 and watermark 3, respectively; *A* is Gaussian measurement matrix; D_1, D_2, *and* D_3 are DCT coefficients of watermark 1, watermark 2 and watermark 3, respectively.

- Apply SVD on CS measurements of watermark 1, watermark 2 and watermark 3 to get the singular value of CS measurements of watermark 1, watermark 2 and watermark 3, respectively.

$$[U_{Y1}, S_{Y1}, V_{Y1}] = svd(y_1)$$
$$[U_{Y2}, S_{Y2}, V_{Y2}] = svd(y_2) \quad (10)$$
$$[U_{Y3}, S_{Y3}, V_{Y3}] = svd(y_3)$$

In above equation, S_{Y1}, S_{Y2}, and S_{Y3} are the singular value of CS measurements of watermark 1, watermark 2 and watermark 3, respectively; y_1, y_2, *and* y_3 are CS measurements of watermark 1, watermark 2 and watermark 3, respectively.

- Apply RDWT on R channel, G channel, and B channel of host image to get wavelet coefficients of the host image.

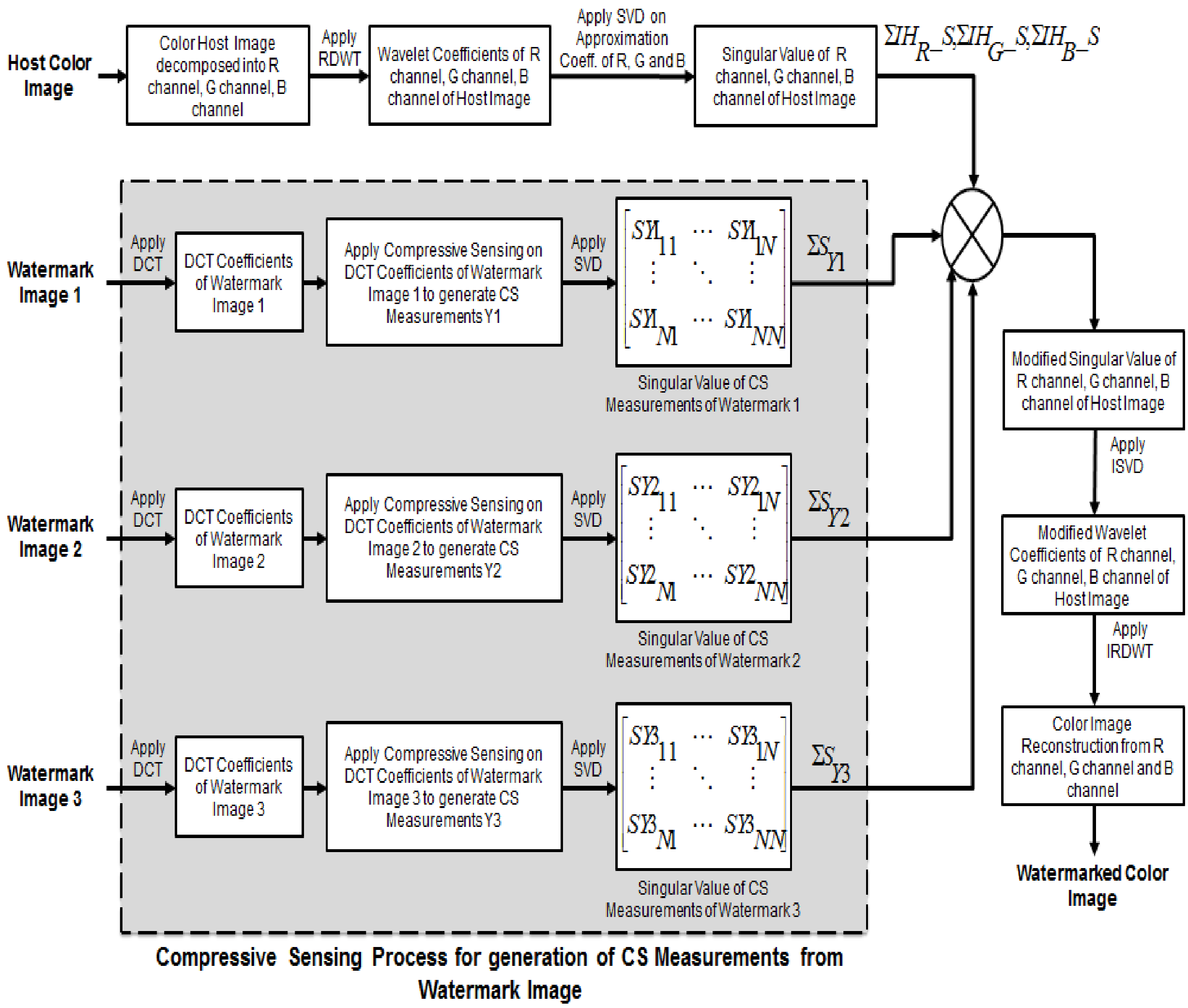


Figure 4: Framework for Proposed Embedding Procedure.

$$[LL1, LH1, HL1, HH1] = RDWT(IH\_Red)$$
$$[LL2, LH2, HL2, HH2] = RDWT(IH\_Green) \quad (11)$$
$$[LL3, LH3, HL3, HH3] = RDWT(IH\_Blue)$$

In above equation, *IH_Red*, *IH_Green*, and *IH_Blue* are R channel, G channel and B channel of the color host image, respectively.

- Then SVD is applied on LL subband to get the singular value of approximation wavelet coefficients of the host image.

$$[IH_R\_U, IH_R\_S, IH_R\_V] = svd(LL1)$$
$$[IH_G\_U, IH_G\_S, IH_G\_V] = svd(LL2) \quad (12)$$
$$[IH_B\_U, IH_B\_S, IH_B\_V] = svd(LL3)$$

In above equation, IH_R_S, IH_G_S, and IH_B_S are the singular value of LL subband of R channel, G channel and B channel of the color host image, respectively.

- The singular value of approximation wavelet coefficients of host image is modified according to the singular value of CS measurements of watermark1, watermark 2 and watermark 2 using gain factor.

$$S1 = IH_R\_S + (k \times S_{Y1})$$
$$S2 = IH_G\_S + (k \times S_{Y2}) \quad (13)$$
$$S3 = IH_B\_S + (k \times S_{Y3})$$

In above equation, *S1*, *S2*, and *S3* have modified the singular value of LL subband of R channel, G channel and B channel of the color host image, respectively; *k* is a gain factor.

- Apply inverse SVD on modified singular value to get modified LL subband of R channel, G channel and B channel of the color host image.

$$new\_LL1 = IH_R\_U * S1 * IH_R\_V'$$
$$new\_LL2 = IH_G\_U * S2 * IH_G\_V' \quad (14)$$
$$new\_LL3 = IH_B\_U * S3 * IH_B\_V'$$

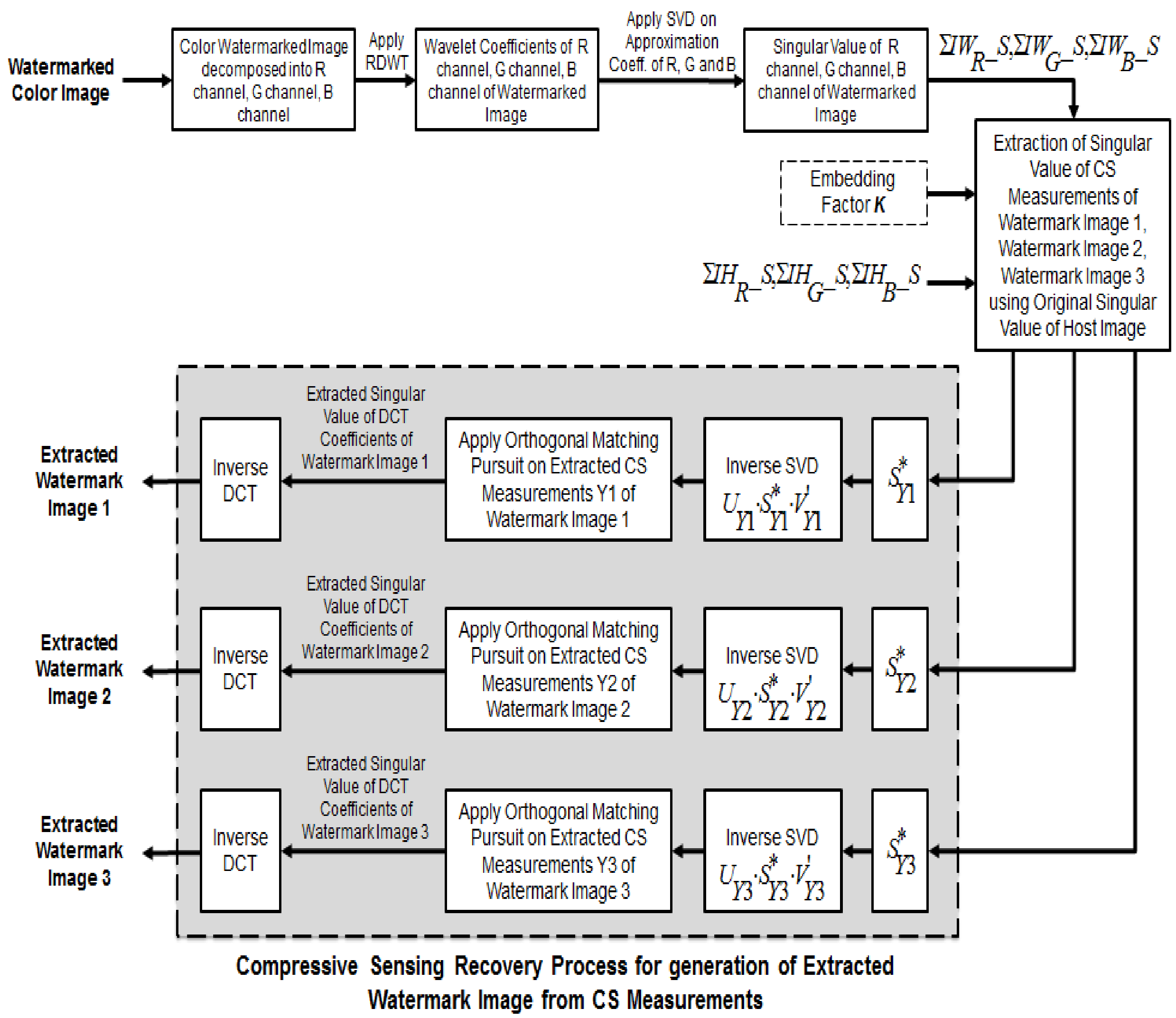


Figure 5: Framework for Proposed Extraction Procedure.

In above equation, *new_LL1*, *new_ LL2*, and *new_LL3* have modified LL subband of R channel, G channel and B channel of the color host image, respectively.

- The inverse RDWT is applied on modified LL subband with unmodified subbands to get modified R channel, G channel and B channel of the color host image.

$$WA\_R = IRDWT(new\_LL1, LH1, HL1, HH1)$$
$$WA\_G = IRDWT(new\_LL2, LH2, HL2, HH2) \quad (15)$$
$$WA\_B = IRDWT(new\_LL3, LH3, HL3, HH3)$$

In above equation, *WA_R*, *WA_G*, and *WA_B* are modified R channel, G channel and B channel of the color host image, respectively.

- Finally, the color image reconstruction is applied on modified RGB channels to get watermarked color image *IW*.

4.2 Multiple watermark extraction procedure

For extraction of the watermark, from watermarked image, the measurement matrix, orthogonal matrices U, V of CS measurements is required. The OMP algorithm [44] is used to the extraction of DCT coefficients of multiple watermarks from its extracted CS measurements values. Figure 5 shows the block diagram for the proposed extraction procedure and the mathematical steps for watermark extraction are given below.

- Take watermarked image and decomposed into R channel, G channel, and B channel. Apply redundant DWT on the watermarked image *IW*, to get the modified wavelet coefficients of R channel, G channel and B channel, respectively.

$$[LLW1, LHW1, HLW1, HHW1] = RDWT(IWR)$$
$$[LLW2, LHW2, HLW2, HHW2] = RDWT(IWG) \quad (16)$$
$$[LLW3, LHW3, HLW3, HHW3] = RDWT(IWB)$$

In above equation, *IWR*, *IWG*, and *IWB* are R channel, G channel and B channel of color watermarked image, respectively.

- Apply SVD on LL subband of R channel, G channel and B channel of watermarked image to get the singular value of R channel, G channel and B channel of watermarked image.

$$[IW_R\_U, IW_R\_S, IW_R\_V] = svd(LLW1)$$
$$[IW_G\_U, IW_G\_S, IW_G\_V] = svd(LLW2) \quad (17)$$
$$[IW_B\_U, IW_B\_S, IW_B\_V] = svd(LLW3)$$

In above equation, IW_R_S, IW_G_S, and IW_B_S are the singular value of LL subband of R channel, G channel and B channel of color watermarked image, respectively.

- Extract singular value of CS measurements of multiple watermarks using singular value of RGB channel of host image and singular value of RGB channel of watermarked image with help of gain factor as

$$S^*_{Y1} = (IW_R\_S - IH_R\_S)/k$$
$$S^*_{Y2} = (IW_G\_S - IH_G\_S)/k \quad (18)$$
$$S^*_{Y3} = (IW_B\_S - IH_B\_S)/k$$

In above equation, S^*_{Y1}, S^*_{Y2}, and S^*_{Y3} are extracted singular value of CS measurements of watermark 1, watermark 2 and watermark 3, respectively.

- Then apply inverse SVD on extracted singular value with original U, V to get extracted CS measurements of multiple watermarks information.

$$Ey_1 = W_1\_U * EW_1\_S * W_1\_V'$$
$$Ey_2 = W_2\_U * EW_2\_S * W_2\_V' \quad (19)$$
$$Ey_3 = W_3\_U * EW_3\_S * W_3\_V'$$

In above equation, Ey_1, Ey_2, and Ey_3 are extracted CS measurements of watermark 1, watermark 2 and watermark 3, respectively.

- The OMP algorithm is applied on extracted CS measurements of multiple watermarks information to get DCT coefficients of multiple watermarks.

$$D_1^* = OMP(Ey_1, A)$$
$$D_2^* = OMP(Ey_2, A) \quad (20)$$
$$D_3^* = OMP(Ey_3, A)$$

In above equation, D^*_1, D^*_2, and D^*_3 have extracted DCT coefficients of watermark 1, watermark 2 and watermark 3, respectively; *A* is a measurement matrix.

- Finally applied inverse DCT on extracted DCT coefficients to get multiple watermarks at detector side.

$$w_1^* = idct(D_1^*)$$
$$w_2^* = idct(D_2^*) \quad (21)$$
$$w_3^* = idct(D_3^*)$$

In above equation, w^*_1, w^*_2, and w^*_3 are extracted watermark 1, extracted watermark 2 and extracted watermark 3 at detector side, respectively.

5 Results and discussion

The testing of proposed algorithm using various types of images with quality measures are discussed in this section. The various test images and watermarks are discussed in subsection 5.1. The quality measures such as PSNR, NCC, and payload capacity for proposed algorithm is discussed in subsection 5.2. The performance analysis of proposed algorithm for multiple watermarks is discussed in subsection 5.3. The performance analysis of proposed algorithm for multiple biometric watermarks is discussed in subsection 5.4. The comparison of proposed algorithm with existed algorithms is discussed in subsection 5.5.

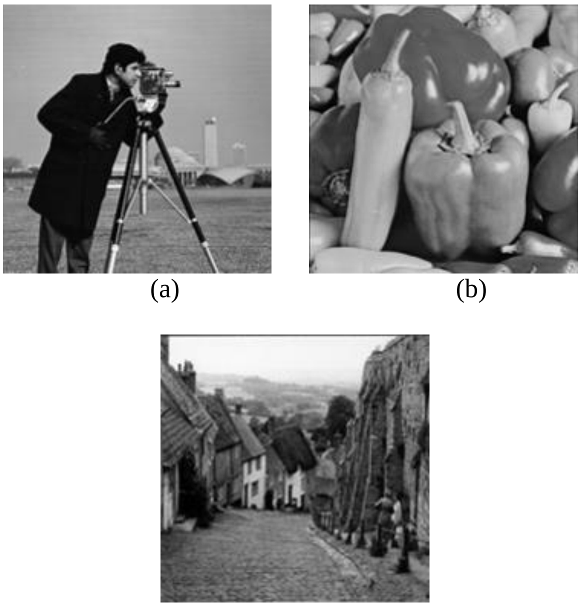
5.1 Test images and watermarks

(a) (b)

Figure 6: Test Host Color Images (a) Lena (b) Mandril.

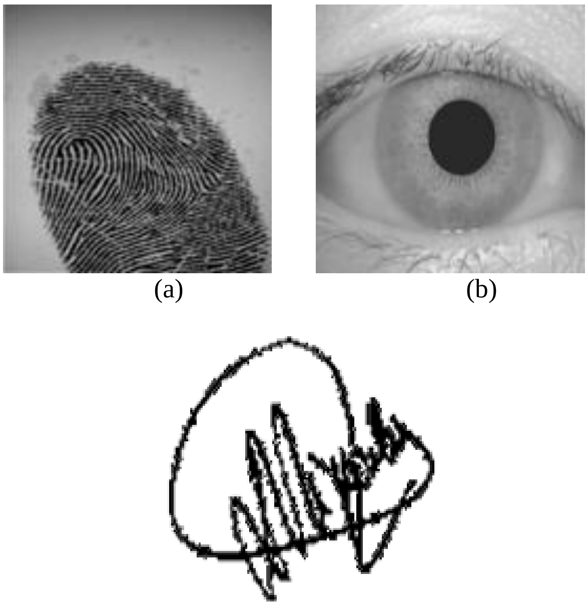
The performance of any watermarking scheme varies with different types of images. Therefore, in this paper, two different types of host color images such as Lena image and mandril image are used. In Figure 6, Lean host image and mandril host image have a size of 176×176 pixels and 128×128 pixels, respectively. The various type of watermarks information is taken in this paper. Figure 7 shows various standard watermark images with various frequency coefficients. The cameraman watermark image (which has low frequency coefficients), peppers watermark image (which has middle-frequency coefficients) and Goldhill watermark image (which has high frequency coefficients) have a size of 176×176 pixels. Figure 8 shows various biometric watermarks images. The fingerprint watermark image, iris watermark image, and sign watermark image have a size of 128×128 pixels.

The performance of proposed algorithm is carried out for different gain factor. The analysis of proposed algorithm is carried out for various watermarking attacks such as JPEG compression; noise addition such as Gaussian noise, Salt-Pepper noise, and speckle noise;



(a) (b) (c)

Figure 7: Test Standard Watermark Images
(a) Cameraman (b) Peppers (c) Goldhill.



(a) (b) (c)

Figure 8: Test Biometric Watermark Images
(a) Fingerprint (b) Iris (c) Sign.

filter attacks such as Mean, median, sharpen and Gaussian low pass filter; geometric attacks such as histogram equalization, rotation, and cropping.

5.2 Quality measures

The perceptual quality of watermarked image is measured by Peak Signal to Noise Ratio (PSNR) [46] and the mathematical equation of PSNR is given in below

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{22}$$

In above equation, MSE is defined as mean square error and given by

$$MSE = \frac{1}{M \times N}\sum_{x=1}^{M}\sum_{y=1}^{N}\{I(x,y) - I^*(x,y)\}^2 \tag{23}$$

In above equation, I and I^* is original host image and watermarked image respectively.

The MSE is measured in general scale while PSNR is measured in logarithmic scale. The high value of PSNR is indicated more imperceptibility of watermarking scheme. The normalized cross correlation (NCC) [46] is used to measure the similarity between original watermark image and extracted watermark image. The mathematic equation for NCC is given in below

$$NCC = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N} w(x,y) \times w*(x,y)}{\sum_{x=1}^{M}\sum_{y=1}^{N} w^2(x,y)} \tag{24}$$

In above equation, w is original watermark image and w^* is extracted watermark image.

The NCC value lies in 0 to 1. When NCC value is 1 then it is indicated the extracted watermark image is exactly similar to the original watermark image. But NCC value is 0 then it is indicated that the extracted watermark image is not similar to the original watermark image. In this paper, PSNR is used for measurement of imperceptibility of proposed watermarking algorithm. NCC is used for measurement of robustness and security of proposed watermarking algorithm.

The payload capacity of any watermarking system can be defined as the amount of watermark information is embedded into host medium. The payload capacity can be calculated by a number of bits embedded in host pixels or a ratio of the size of the watermark to the size of host medium. In this paper, payload capacity is calculated using below equation.

$$PC = \frac{SizeofWatermark}{SizeofHost} \tag{25}$$

In above equation, PC is payload capacity of the watermarking algorithm; the size of watermark and host in pixels.

5.3 Performance analysis of proposed algorithm for multiple watermarks

In the proposed algorithm, CS measurements are generated using DCT coefficients of multiple watermark images. In this proposed algorithm, the wavelet coefficients of R channel, G channel and B channel of color host image are generated using db1 or haar wavelet. The db1 or haar wavelet is basic wavelet, simplest, asymmetric and orthogonal as well as bi-orthogonal in nature. These wavelets are commonly used in watermarking. The singular value of CS measurements

(a) Watermarked Lena Host Image with Multiple Standard Watermark Images

(b) Extracted Cameraman Watermark Image

(c) Extracted Peppers Watermark Image

(d) Extracted Goldhill Watermark Image

Figure 9: Results of Proposed Algorithm for Multiple Standard Watermark Images.

is embedded into the singular value of LL subband of the color host image.

Figure 9 shows the watermarked Lena host image with multiple watermarks and extracted standard watermark images without application of watermarking attacks on watermarked color image using gain factor 0.002 and db1 wavelet.

Table 1 shows PSNR and NCC values for multiple standard watermark images for different gain factor without application of watermarking attacks. The performance analysis of proposed algorithm for multiple standard watermark images against various watermarking attacks is carried out for different gain factor. Table 2 shows the performance of proposed algorithm for multiple standard watermark images under JPEG compression and Gaussian noise addition attack.

Table 3 shows the performance of proposed algorithm for multiple standard watermark images under noise addition attacks such as salt-pepper noise and speckle noise. Table 4 shows the performance of proposed algorithm for multiple standard watermark images under various filters such as median and mean.

Table 5 shows the performance of proposed algorithm for multiple standard watermark images under Gaussian low pass filter attack and sharpening attack. Table 6 and 7 shows the performance of proposed algorithm for multiple standard watermark

Table 1: PSNR and NCC values of Proposed Algorithm for Multiple Standard Watermark Images without Application of Watermarking Attacks.

Gain Factor	PSNR (dB)	NCC 1 for Cameraman Watermark Image	NCC 2 for Peppers Watermark Image	NCC 3 for Goldhill Watermark Image
0.002	43.56	0.9703	0.9822	0.9963
0.003	39.94	0.9555	0.9925	0.9963
0.004	37.44	0.9650	0.9897	0.9904
0.005	34.77	0.9636	0.9927	0.9861

Table 2: Performance of Proposed Algorithm for Multiple Standard Watermark Images under JPEG Compression Attack and Gaussian Noise Addition Attack.

Gain Factor	JPEG Compression (Q = 50)			Gaussian Noise (Variance = 0.001)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9693	0.9844	0.9884	0.9785	0.9917	0.9932
0.003	0.9627	0.9927	0.9900	0.9595	0.9953	0.9947
0.004	0.9644	0.9889	0.9893	0.9657	0.9924	0.9833
0.005	0.9690	0.9921	0.9929	0.9637	0.9903	0.9904

Table 3: Performance of Proposed Algorithm for Multiple Standard Watermark Images under JPEG Compression Attack and Salt-Pepper Noise and Speckle Noise Addition Attack.

Gain Factor	Salt-Pepper Noise (Variance = 0.005)			Speckle Noise (Variance = 0.004)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9585	0.9843	1.0000	0.9674	0.9876	0.9987
0.003	0.9564	0.9907	0.9874	0.9742	0.9888	0.9946
0.004	0.9656	0.9904	0.9884	0.9662	0.9880	0.9905
0.005	0.9676	0.9904	0.9875	0.9694	0.9925	0.9873

Table 4: Performance of Proposed Algorithm for Multiple Standard Watermark Images under Median Filter Attack and Mean Filter Attack.

Gain Factor	Median Filter (Size of Filter Mask = 3×3)			Mean Filter (Size of Filter Mask = 3×3)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9584	0.9831	0.9948	0.9864	0.9934	0.9914
0.003	0.9614	0.9930	0.9975	0.9599	0.9939	0.9962
0.004	0.9664	0.9895	0.9918	0.9642	0.9941	0.9966
0.005	0.9636	0.9941	0.9923	0.9665	0.9884	0.9847

Table 5: Performance of Proposed Algorithm for Multiple Standard Watermark Images under Gaussian Low Pass Filter Attack and Sharpening Attack.

Gain Factor	Gaussian Low Pass Filter (Size of Filter Mask = 3×3)			Sharpening Attack		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9596	0.9798	0.9963	0.9461	0.9804	0.9989
0.003	0.9572	0.9914	0.9874	0.9577	0.9900	0.9898
0.004	0.9658	0.9854	0.9846	0.9693	0.9872	0.9908
0.005	0.9668	0.9917	0.9864	0.9674	0.9938	0.9888

images under rotation attack, cropping attack, and histogram equalization attack.

The NCC value is above 0.94 shown in Table 2 to 7 in the case of different type of watermarking attacks for color host image with multiple standard watermark images. This situation indicated that the algorithm can provide robustness against various type of watermarking attacks for multiple standard watermark images.

5.4 Performance analysis of proposed algorithm for multiple biometric watermarks

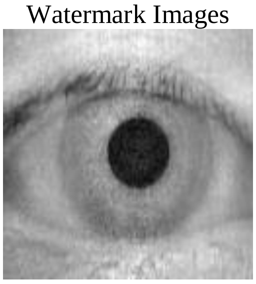
In the proposed algorithm, CS measurements are generated using DCT coefficients of multiple biometric watermark images. In this proposed algorithm, the wavelet coefficients of R channel, G channel and B channel of color host image are generated using db1 wavelet. The singular value of CS measurements is embedded into the singular value of LL subband of the color host image.

Figure 10 shows the watermarked mandril host image with multiple biometric watermarks and extracted biometric watermark images without application of watermarking attacks on watermarked color image using embedding factor 0.002 and db1 wavelet.

Table 8 shows PSNR and NCC values for multiple biometric watermarks for different embedding factor without application of watermarking attacks. The performance analysis of proposed algorithm for multiple biometric watermark images against various watermarking attacks is carried out for different gain factor. Table 9 shows the performance of proposed algorithm for multiple biometric watermark images under JPEG compression and Gaussian noise addition attack.

(a) Watermarked Mandril Host Image with Multiple Biometric Watermark Images

(b) Extracted Fingerprint Watermark Image



(c) Extracted Iris Watermark Image

(d) Extracted Sign Watermark Image

Figure 10: Results of Proposed Algorithm for Multiple Biometric Watermark Images.

Table 10 shows the performance of proposed algorithm for multiple biometric watermark images under noise addition attacks such as salt-pepper noise and speckle noise. Table 11 shows the performance of proposed algorithm for multiple biometric watermark images under various filters such as median and mean.

Table 12 shows the performance of proposed algorithm for multiple biometric watermark images under Gaussian low pass filter attack and sharpening

Table 9: Performance of Proposed Algorithm for Multiple Standard Watermark Images under Rotation Attack and Cropping Attack.

Gain Factor	Rotation Attack			Cropping Attack		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9864	0.9891	0.9929	0.9633	0.9804	0.9974
0.003	0.9749	0.9884	0.9878	0.9651	0.9920	0.9891
0.004	0.9679	0.9913	0.9958	0.9666	0.9879	0.9908
0.005	0.9637	0.9901	0.9813	0.9657	0.9932	0.9951

Table 10: Performance of Proposed Algorithm for Multiple Standard Watermark Images under Histogram Equalization Attack.

Gain Factor	Histogram Equalization Attack		
	NCC 1	NCC 2	NCC 3
0.002	0.9400	0.9829	0.9989
0.003	0.9604	0.9919	0.9890
0.004	0.9710	0.9950	0.9855
0.005	0.9677	0.9919	0.9905

Table 11: PSNR and NCC values of Proposed Algorithm for Multiple Biometric Watermark Images without Application of Watermarking Attacks.

Gain Factor	PSNR (dB)	NCC 1 for Fingerprint Watermark Image	NCC 2 for Iris Watermark Image	NCC 3 for Sign Watermark Image
0.002	43.15	0.9509	0.9993	0.9714
0.003	39.17	0.9612	1.0000	0.9726
0.004	36.43	0.9653	0.9981	0.9717
0.005	34.19	0.9601	0.9990	0.9700

Table 12: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under JPEG Compression Attack and Gaussian Noise Addition Attack.

Gain Factor	JPEG Compression (Q = 50)			Gaussian Noise (Variance = 0.001)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9474	0.9919	0.9753	0.9435	0.9946	0.9742
0.003	0.9603	1.0000	0.9747	0.9595	1.0000	0.9763
0.004	0.9631	0.9992	0.9726	0.9672	0.9988	0.9742
0.005	0.9572	0.9971	0.9689	0.9599	0.9961	0.9696

Table 13: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under JPEG Compression Attack and Salt-Pepper Noise and Speckle Noise Addition Attack.

Gain Factor	Salt-Pepper Noise (Variance = 0.005)			Speckle Noise (Variance = 0.004)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9436	0.9985	0.9725	0.9498	0.9959	0.9772
0.003	0.9598	0.9897	0.9725	0.9603	1.0000	0.9745
0.004	0.9622	0.9983	0.9712	0.9628	0.9956	0.9713
0.005	0.9583	0.9994	0.9677	0.9589	0.9951	0.9707

Table 14: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under Median Filter Attack and Mean Filter Attack.

Gain Factor	Median Filter (Size of Filter Mask = 3×3)			Mean Filter (Size of Filter Mask = 3×3)		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9460	1.0000	0.9731	0.9447	1.0000	0.9718
0.003	0.9572	1.0000	0.9741	0.9592	0.9908	0.9738
0.004	0.9640	0.9971	0.9724	0.9634	0.9962	0.9728
0.005	0.9579	0.9942	0.9658	0.9586	1.0000	0.9695

Table 15: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under Gaussian Low Pass Filter Attack and Sharpening Attack.

Gain Factor	Gaussian Low Pass Filter (Size of Filter Mask = 3×3)			Sharpening Attack		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9443	1.0000	0.9741	0.9534	1.0000	0.9755
0.003	0.9591	1.0000	0.9746	0.9565	1.0000	0.9735
0.004	0.9604	1.0000	0.9705	0.9621	0.9973	0.9706
0.005	0.9556	0.9945	0.9712	0.9566	0.9996	0.9708

Table 16: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under Rotation Attack and Cropping Attack.

Gain Factor	Rotation Attack			Cropping Attack		
	NCC 1	NCC 2	NCC 3	NCC 1	NCC 2	NCC 3
0.002	0.9512	0.9949	0.9749	0.9455	1.0000	0.9717
0.003	0.9630	0.9955	0.9719	0.9640	1.0000	0.9736
0.004	0.9646	0.9998	0.9713	0.9615	0.9950	0.9715
0.005	0.9577	0.9995	0.9678	0.9545	0.9998	0.9669

attack. Table 13 and 14 shows the performance of proposed algorithm for multiple biometric watermark images under rotation attack, cropping attack, and histogram equalization attack.

The NCC value is above 0.94 shown in Table 9 to 14 in the case of different type of watermarking attacks for color host image with multiple biometric watermark images. This situation indicated that the algorithm can

Table 17: Performance of Proposed Algorithm for Multiple Biometric Watermark Images under Rotation Attack and Cropping Attack.

Gain Factor	Histogram Equalization Attack		
	NCC 1	NCC 2	NCC 3
0.002	0.9423	1.0000	0.9730
0.003	0.9601	1.0000	0.9721
0.004	0.9616	0.9940	0.9725
0.005	0.9570	1.0000	0.9693

Table 18: Comparison of Proposed Algorithm with Existed Algorithms.

Techniques	Existed Algorithm in [25]	Existed Algorithm in [41]	Proposed Algorithm
Type of Multiple Watermarking	Successive	-	Composite
Host Medium	Grayscale Image	Grayscale Image	Color Image
Type of Watermark Information	Face, Speech, and Sign	Grayscale Image	Grayscale Image, Fingerprint, Iris and Sign
Number of Watermarks	Three	Single	Three
Used Signal Processing Transform	DWT and DCT	RDWT and SVD	RDWT, SVD, and DCT
CS theory is applied on Watermark Image	No	No	Yes
PSNR (dB)	33.2819	37.52	43.56

provide robustness against various type of watermarking attacks for multiple biometric watermark images.

After obtaining results of proposed algorithm for multiple watermarks, it is clearing seen that this algorithm can be applied any type of watermark information. The NCC value obtained for various watermarking attacks are above 0.90 which is indicated this algorithm provides robustness against any manipulation. This situation indicated that this algorithm can be used for security of multimedia data when it is transferred over a non-secure channel. This algorithm is also used in a multimodal biometric system where multiple biometric data can be secure when it is transferred over a communication channel between two modules.

5.5 Comparison of proposed algorithm with existed algorithms

The comparison of proposed algorithm with existed algorithms with various features is given in Table 15.

The comparison shows that the CS theory is applied on multiple watermarks in proposed algorithm before embedding which is not applied in existed algorithms. The PSNR value of proposed algorithm is better than existed algorithms in the literature. The proposed algorithm can be used for any multiple watermarks such as standard images and biometric images while algorithm in [25] is used for biometric images and algorithm in [41] is used for the standard image.

6 Conclusion

Nowadays, the payload capacity and multiple watermarks inserted ability of watermarking algorithms are considered as important parameters. So in this paper, multiple watermarks based watermarking algorithm with high payload capacity is presented. A watermarking algorithm using redundant DWT, SVD and compressive sensing for multiple watermarks protection is designed and analyzed for the security of multiple watermarks. The proposed algorithm is also shown application on CS theory for generation of multiple CS measurements of watermark image. The CS theory is providing protection to multiple watermark images before embedding in proposed algorithm. Our algorithm is flexible and may be used for any type of watermark information such as standard image and biometric image. This proposed algorithm can be used for security of multiple watermark information when it is transferred over the non-secure communication channel.

An experimental is implemented using various color host images and watermarks information. Two types of host images and six types of watermark images are used in the experiments. The proposed algorithm has generally overcome the limitation of existed watermarking algorithms. The experiments also show that the proposed algorithm can provide robustness against various watermarking attacks such as JPEG compression, the addition of noise, filter, sharpening, histogram equalization, geometric attack such as rotation, cropping. The proposed algorithm is performed better than existed algorithms available in the literature based on PSNR values.

The limitation of proposed algorithm is that original host image is required at detector side for extraction of watermark information. So this algorithm is a non-blind watermarking algorithm in nature. In the future, the algorithm is designed and analyzed for various data such as speech signal, ECG signal, digital video and digital audio signal. Also, a hardware implementation of proposed algorithm is designed using various DSP platform and FPGA kits.

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