Robust watermarking technique using back propagation neural network: a security protection mechanism for social applications

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Abstract: In this paper, an algorithm for digital watermarking based on discrete wavelet transforms (DWTs) and singular value decomposition (SVD) has been proposed. In the embedding process, the host colour image is decomposed into third-level DWT. Low frequency band (LL3) is transformed by SVD. The watermark image is also transformed by SVD. The S vector of watermark information is embedded in the S component of the host image. Watermarked image is generated by inverse SVD on modified S vector and original U, V vectors followed by inverse DWT. Watermark is extracted using an extraction algorithm. In order to enhance the robustness performance of the image watermark, back propagation neural network (BPNN) is applied to the extracted watermark to reduce the effects of different noise applied on the watermarked image. Results are obtained by varying the gain factor and size of the cover and watermark image, experimental results are provided to illustrate that the proposed method is able to withstand a variety of signal processing attacks and has been found to be giving superior performance for robustness and imperceptibility compared to existing methods suggested by other authors.

Keywords: image watermarking; discrete wavelet transform; DWT; singular value decomposition; SVD; back propagation neural network; BPNN; normalised correlation; NC; social applications.

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1 Introduction

Nowadays growth in technology such as computers and computer network offers widespread use of multimedia contents such as digital image, audio and video. This growth has also made easy duplication and distribution of this multimedia data. Therefore, protection of multimedia content has become essential and difficult job. Digital watermarking is one of the new, popular and efficient techniques for multimedia data protection. In this scheme, a document called watermark is embedded into the digital data to protect it from unauthorised use in various social applications such as copy protection, tamper detection, broadcast monitoring, content archiving, fingerprinting, healthcare, cyber watermarking and content authentication (Bender et al., 1996; Provos and Honeyman, 2003; Cheddad et al., 2010; Singh and Chadha, 2013; Tagare and Kuri, 2015; Agbaje et al., 2015; Singh et al., 2015a). In addition, digital watermarks are also used to protect state driver licenses by providing covert and machine readable layer of security to fight against various issues such as digital counterfeiting, fraud, identity theft, etc. (http://www.digitalwatermarkingalliance.org/faqs.asp). The main concern of watermarking schemes is that the watermark should not affect the quality of cover image and it should be robust for different signal processing attacks. The watermarking techniques are classified on the basis of permanency, visibility, detection and domain. According to domain, watermarking techniques can be classified as spatial domain and transform domain watermarking techniques. In spatial domain techniques which include least significant bit (LSB), correlation-based technique, predictive coding schemes and patchwork algorithm (Singh, 2015; Potdar et al., 2005 watermark is embedded by modifying values of pixels. It is simple technique and requires less time and computational complexity, however it is less robust against signal processing attacks.

In transform domain watermarking such as discrete cosine transform (DCT), discrete wavelet transform (DWT), discrete Fourier transform (DFT) and singular value decomposition (SVD) (Parashar and Singh, 2014; Ahmidi and Safabakhsh, 2004; Ahmed et al., 2009), cover image is converted into transform domain and then watermark is embedded into transformed coefficients. The important characteristics of the watermarks are robustness, imperceptibility, capacity, computational cost and security (Singh and Chadha, 2013). These characteristics are very important for any watermarking system. However, there exists some tradeoff between the performance factors robustness, imperceptibility and capacity. Robustness is achieved when modifications made to host image by watermark are significantly large. It also affects the imperceptibility of the image because these modifications can be seen by human eyes. Therefore, some optimisation techniques are required to balance these performance factors. Recently, BPNN techniques have been used to balance robustness and imperceptibility. Artificial intelligence (AI) techniques such as genetic algorithm (GA), differential evolution (DE), neural networks (NN), clonal selection algorithm (CSA) and particle swarm optimiser (PSO) (Zhicheng et al., 2006; Aslantas, 2009; Aslantas et al., 2008, 2009; Ali et al., 2014; Yen and Huang, 2015) are used as an optimisation technique to search optimal sub-bands and coefficients in transform domain to embed watermark with different scaling factors. In addition, these techniques can be used as optimisation techniques to remove some round off errors when coefficients in transform domain are transformed to spatial domain. Different image watermarking techniques using neural networks have been proposed (Shi-Chun et al., 2002; Yang et al., 2010; Yu et al., 2001; Vafaei et al., 2013). For a detailed description on these approaches, interested readers may directly refer to them.

1.1 Related literature on proposed work and research gaps

The methods based on the related work are discussed below:

Aslantas et al. (2008) introduced an optimal DWT-SVD-based image watermarking technique using particle swarm optimiser (PSO). In the embedding process, the cover image is decomposed by DWT and then SVD is applied on the selected sub-band of the DWT cover. Further, the singular value of the cover image is modified with the singular value of the watermark image. Modifications in the cover image coefficients are optimised using PSO to obtain the highest possible robustness without losing the visual quality of the watermarked image. Experimental results shown the method is robust for different attacks with acceptable quality of the watermarked image. Ali et al. (2014) proposed an innovative watermarking scheme based on Differential Evolution and two popular transform domain techniques, DWT-SVD. In the embedding process, the cover image is decomposed by DWT and then SVD is applied on the selected sub-band (LL and HH) of the DWT cover. The singular value of the selected sub-band of cover is modified with directly with the binary watermark image. Also, the proposed method offer one of the solutions of false positive problem as suffer by SVD. Experimental results shown that the method offers good imperceptibility and strong robustness. Yang et al. (2010) proposed a colour image watermarking method based on DWT and BPNN. In the embedding process, three identical watermarks of size 40 × 30 have been adaptively embedded into the low frequency sub-bands generated from three channels (R, G and B) for a colour image of size 512 × 512 respectively. The experimental results have been shown that the proposed scheme is robust against various kinds of signal processing attacks. In addition, the performance of the method proposed by Yang et al. is better than other reported technique (Yu et al., 2001).

Vafaei et al. (2013) proposed a blind watermarking method based on DWT and feed forward neural networks (FNN). In the embedding process, third level DWT applied on cover image and divides the selected sub-bands into different blocks. For improving the robustness of the binary watermark of size 32 × 32, the watermark is embedded repetitively into the selected DWT coefficients. Experimental results demonstrate that the proposed method offer good visual quality of the watermarked image and robust against different kinds of signal processing attacks. Yen and Huang (2015) proposed a digital watermarking scheme based on DCT and BPNN. In the embedding process, DCT has been applied on the cover image of size 256 × 256 and the watermark of size 32 × 32 is embedded into the mid frequency region. Further, the embedded image contains the DCT coefficients were converted back to the spatial domain by using the inverse DCT. The simulation results indicated that the method is found to be robust for different attacks.

From the above it is clear that image watermarking using DWT and SVD have been found to give high robustness, imperceptibility and capacity.

Various factors such as imperceptibility, robustness, capacity and security need to be considered in the watermarking methods. Depending upon the application requirements there can be trade-off between these factors. Thus, there is need to develop effective watermarking methods that can offer good trade-off between these parameters/factors for different applications. Further, the security factor of watermarking methods can also differ slightly depending on the application. Minimisation of the computational complexity is important for practical implementation.

1.2 Main contribution of the work

In this research, the robustness is achieved by using fusion of DWT, SVD and BPNN-based image watermarking techniques which offer a good trade-off between important parameter/factor.

This paper presents a hybrid approach (DWT and SVD) for digital image watermarking using BPNN. Cover image is decomposed using third-level DWT to obtain (LL3, LH3, HL3 and HH3) different sub-bands. LL3 sub-band is selected for embedding the image watermark. It is evident watermarks containing important information such requiring more robustness are embedded in higher level DWT sub-bands (Singh et al., 2015b). Results are obtained by varying the gain factor, size of watermark, and the different cover image modalities. Experimental results are provided to illustrate that the proposed method is able to withstand a known attacks. The method is also compared with other method and found to be robust for the considered attacks. The following observation are apparent:

- The DWT and SVD are the popular techniques used for watermarking so their fusion makes a very attractive watermarking technique. Due to its excellent spatio-frequency localisation properties, the DWT is very suitable to identify areas in the cover image where a watermark can be imperceptibly embedded (Singh et al., 2015b). One of attractive mathematical properties of SVD is that slight variations of singular values do not affect the visual perception of the cover image (Singh et al., 2015b), which motivates the watermark embedding procedure to achieve better performance in terms of imperceptibility, robustness and capacity as compared to DWT and SVD applied individually.
- To improve the robustness performance of the proposed method, back propagation neural network (BPNN) is applied to the extracted watermark which gives the higher normalised correlation (NC) values compared to without using the BPNN.
- In Table 4, the robustness performance of the proposed method is compared with other reported techniques (Jagadeesh et al., 2013; Li et al., 2007) and it is found that the proposed method offers superior NC performance.

Therefore the proposed method may find potential application in prevention of digital document theft/alteration in different applications.

2 Theoretical background

The proposed watermarking method based on DWT and SVD using BPNN. Hence, a brief description of these concepts is included in the given below sections.

2.1 Discrete wavelet transform

DWT of digital image provides multi-resolution representation of an image which helps in interpreting image information (Barni and Bartolini, 2001; Deb et al., 2012). It transforms the two-dimensional digital image into four quadrants of different frequencies i.e. LL1, LH1, HL1, HH1. The low frequency part LL1 can be split again into more quadrants of high and low frequencies i.e. LL2, LH2, HL2 and HH2 and LL2 can be further decomposed into LL3, LH3, HL3 and HH3 until the signal is fully decomposed (Kashyap and Sinha, 2012; Kaur and Jindal, 2013; Ganic and Eskicioglu, 2004). The coefficients obtained by applying DWT to host image (H) are (Parashar and Singh, 2014):

$$H_{LL}^{I} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} g(x)g(y)H_{LL}^{I-1}(2u-x)(2v-y) \tag{1}$$

$$H_{LH}^{I} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} g(x)h(y)H_{LL}^{I-1}(2u-x)(2v-y) \tag{2}$$

$$H_{HL}^{I} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} h(x)g(y)H_{LL}^{I-1}(2u-x)(2v-y) \tag{3}$$

$$H_{HH}^{I} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} h(x)h(y)H_{LL}^{I-1}(2u-x)(2v-y) \tag{4}$$

Here u, v = 1, 2, 3…..N – 1, *I* is the level of DWT transform and h(n), g(n) are the impulse responses.

2.2 Singular value decomposition

The SVD decomposes matrix of host image into three rectangular matrices, i.e., U, S and transpose (T) of V. U and V are orthogonal square matrices in which columns are left and right singular vectors. These singular vectors represent the geometry of an image. S is diagonal matrix whose diagonal entries is singular values and is in descending order. These singular values represent the brightness of an image. SVD is very efficient in representing the intrinsic properties of an image (Liu and Tan, 2002; Chang et al., 2005). Let I is square matrix then SVD can be represented as (Chung et al., 2007; Fan et al., 2008):

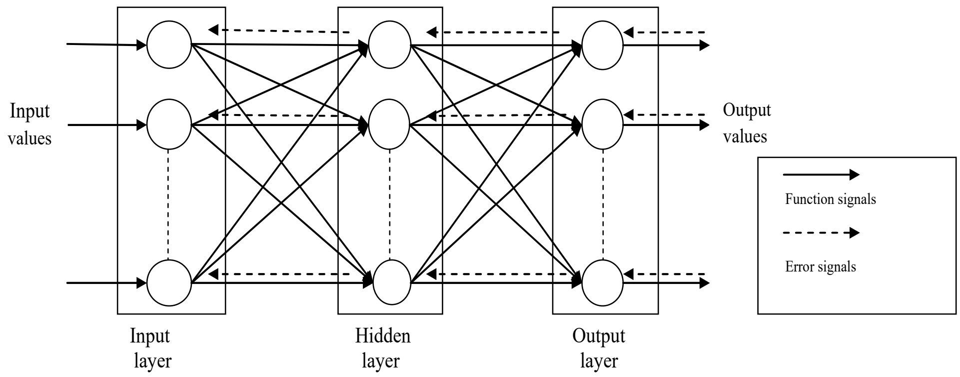
$$I = USV^{T} \tag{5}$$

2.3 Back propagation neural network

Artificial neural networks are based on the structure of human brain and used for complicated problems of pattern recognition, clustering and classification. A typical neural network consists of an input layer, hidden layers and output layer. Different algorithms for training BPNN are steepest descent method, adaptive learning rate, conjugate gradient, quasi-Newton and Levenburg-Marquardt (LM) algorithm (Ali et al., 2014; Yen and Huang, 2015; Hagan and Menhaj, 1994). The iteration of back propagation learning algorithm can be written as (Hagan and Menhaj, 1994):

$$X_{k+1} = X_k - a_k g_k \tag{6}$$

Figure 1 Back propagation neural network



Source: Ali et al. (2014) and Yang et al. (2010)

Here X_k is current vector of weights and biases, a_k is learning rate and g_k is current gradient. In this paper, LM algorithm is used which uses batch mode to implement gradient descent and it is ten to hundred times faster than standard algorithms using incremental mode. Like quasi-Newton algorithm, LM algorithm approach second order training speed without computing Hessian matrix. The Hessian matrix (H) can be approximated as

$$H = J^T J \tag{7}$$

The gradient (g) can be calculated as

$$g = J^T e \tag{8}$$

Here 'J' is the Jacobian matrix which contains first order derivative of network errors with respect to biases and weights. J^T is transpose of Jacobian matrix and e is vector of network errors.

The LM algorithm uses following Newton like update to approximate the Hessian matrix:

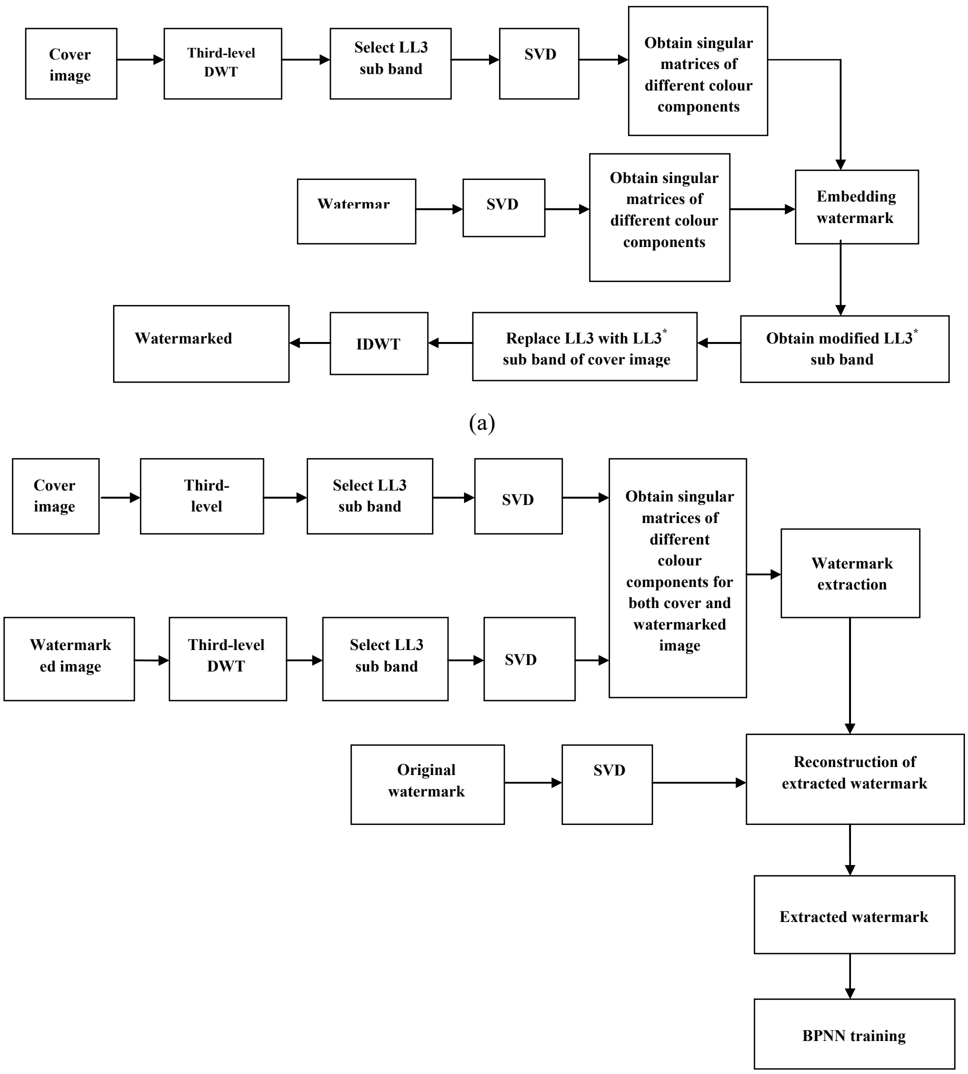
$$x_{k+1} = x_k - \left[J^T J + \mu I\right]^{-1} J^T e \tag{9}$$

Here μ is a scalar which is used to determine whether gradient descent with smaller step size or Newton's method using Hessian matrix will be used. If μ = 0, it becomes Newton's method otherwise it becomes gradient descent with smaller step size (Vogl et al., 1998; Jacobs, 1988; Rumelhart et al., 1986).

3 Proposed algorithm

The proposed algorithm has two different parts, the embedding and extraction process. Figures 2(a) and 2(b) illustrates the watermark embedding and extraction process respectively. The algorithmic steps are discussed below.

Figure 2 (a) Watermark embedding and (b) watermark extraction process



(b)

3.1 Watermark embedding process

1. Apply third-level DWT transform on cover image to decompose it into corresponding sub bands.
2. Select LL3 sub band and apply SVD on red (R), green (G) and blue (B) components of cover image to partition it into three matrices U, S and V.

   $$A_{ci} = U_{ci}S_{ci}V_{ci}^{T} i = R, \text{ G and B} \tag{10}$$

3. Apply SVD on red (R), green (G) and blue (B) components of watermark image to obtain its corresponding matrices similar to step 2.

   $$A_{wi} = U_{wi}S_{wi}V_{wi}^{T} i = R, \text{ G and B} \tag{11}$$

4. Modify the singular values of different colour components of LL3 sub band of cover image with singular values of different colour components of watermark image. Here k is defined as the scaling factor with which watermark image is embedded into host image.

   $$S_{wati} = S_{ci} + k * S_{wi} \tag{12}$$

5. Obtain modified $LL3^{*}$ sub band using following equations.

   $$A_{wati} = U_{ci} * S_{wati} * V_{ci}^{T} \tag{13}$$

   These arrays (A_{watr}, A_{watg}, A_{watb}) are concatenated in three dimension to obtain modified $LL3^{*}$ sub-band.

6. Change LL3 sub band of cover image with the modified $LL3^{*}$ sub band at third level and apply inverse discrete wavelet transform (IDWT) to get watermarked image A_{wat}.
7. Apply attacks and noise to the watermarked image to check the robustness of the proposed algorithm.

3.2 Watermark extraction process

1. Apply third-level DWT transform on cover image to decompose it into corresponding sub bands.
2. Select LL3 sub-band and apply SVD on red (R), green (G) and blue (B) components of cover image to partition it into three matrices U, S and V.

   $$A_{ci} = U_{ci}S_{ci}V_{ci}^{T} i = R, \text{ G and B} \tag{14}$$

4. Apply SVD on red (R), green (G) and blue (B) components of watermark image to obtain its corresponding matrices similar to step 2.

   $$A_{wi} = U_{wi}S_{wi}V_{wi}^{T} \tag{15}$$

5. Apply step 1 and step 2 to watermarked image to obtain its corresponding SVD matrices for LL3 sub band.

$$A_{wati} = U_{wati} S_{wati} V_{wati}^{T} \quad (16)$$

6 Obtain singular values of watermark image from the singular values of LL3 sub band of watermarked image and cover image by using following equations:

$$S_{wi}^{*} = \left(S_{wati} - S_{ci}\right) / k \quad (17)$$

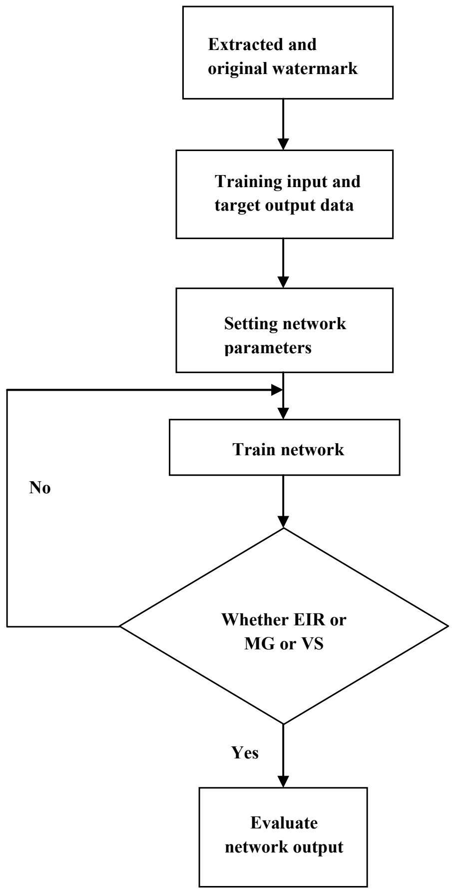
7 Obtain extracted watermark using these equations:

$$A_{ewi} = U_{wi} * S_{wi}^{*} * V_{wi}^{T} \quad (18)$$

These arrays (A_{ewr}, A_{ewg}, A_{ewb}) are concatenated in three dimension to obtain extracted watermark image $A_{ew.}$

8 BPNN is then applied to extracted watermark to remove noise and interferences in order to improve its robustness. Figure 3 shows the BPNN training process.

Figure 3 BPNN training process



Notes: EIR: error in range
MG: minimum gradient reached
VS: validation stop

4 Experimental results and analysis

We describe the performance of the combined DWT-SVD watermarking algorithm using BPNN. Different colour images from internet were tested as cover and watermark image of different size was used to demonstrate the experimental results. The colour peppers image of size 512 × 512 as cover image and the logo image of size 64 × 64 is consider as watermark image. Also, BPNN is applied to the extracted watermark to achieve the better robustness performance of the proposed method against different signal processing attacks. Strength of watermark is varied by varying the gain factor in the watermarking algorithm. For testing the robustness and quality of the watermarked image of the proposed scheme MATLAB is used. Also, evaluate the quality of watermarked image by the parameter PSNR and robustness of the proposed algorithm by NC (Singh et al., 2015b). Figures 4(a) to 4(c) shows the cover pepper image, watermark logo image and watermarked images respectively. Figures 5(a) and 5(b) shows the extracted watermark without and with using the BPNN training respectively. The PSNR and NC performance of the proposed method is shown in Tables 1 to 3. Table 4 shows the NC performance of the proposed method is better than the existing (Jagadeesh et al., 2013; Li et al., 2007) methods. Figures 6 to 9 shows the graphical representation of Tables 1 to 4 respectively.

Figure 4 (a) Cover image (b) watermark image and (c) watermarked image (see online version for colours)

(a) (b) (c)

Figure 5 Extracted logo watermark (a) without and (b) with BPNN training (see online version for colours)

(a) (b)

In Table 1, the PSNR and NC performance of the proposed method has been evaluated without any noise attack. Without using the BPNN, the maximum PSNR value is 36.26 dB where the NC value is 0.19 at gain factor = 0.01. However, the NC value has been obtained as 0.82 with BPNN at the same gain. With BPNN, the maximum NC value is 0.98 at gain factor = 0.1. However, the NC value has been obtained as 0.90 without using BPNN at the same gain. Hence, the NC performance of the proposed method has been improved up to 76.82% with BPNN. We found that larger the gain factor, stronger the robustness and smaller the gain factor, better the image quality.

Table 2 shows the effect of cover image, proposed algorithm was tested for other images like earth, fruits, sky, medical and Lena images. With BPNN, the highest NC value have been obtained with Earth image at gain = 0.1. However, the highest NC value has been obtained with the same cover image without using the BPNN. Here, the ratio of the size of the cover and watermark image is very important. Hence, the NC performance of the proposed method has been improved up to 20.62% with BPNN.

Table 1 PSNR and NC performance of the proposed method at different gain

SN	*Gain factor*	*Without using BPNN*		*With BPNN*	*Improvement in NC values (%)*
		PSNR	*NC*	*NC*	
1	0.01	36.26	0.19	0.82	76.82
2	0.05	35.83	0.88	0.97	9.28
3	0.1	34.78	0.90	0.98	8.16

Table 2 NC and PSNR performance for different size of cover and watermark image at gain = 0.1

SN	*Cover image*	*Watermark image*	*Cover image size*	*Watermark image size*	*PSNR (dB)*	*NC*	*NC (using BPNN)*	*Improvements in NC values (%)*
1	Peppers	Logo_1	512 × 512	64 × 64	34.78	0.90	0.98	8.16
2	Earth	Logo_2	1,024 × 1,024	128 × 128	32.31	0.98	0.99	1.01
3	Fruits	Logo_3	256 × 256	32 × 32	30.41	0.85	0.96	11.46
4	Sky	Logo_4	128 × 128	16 × 16	34.35	0.80	0.94	14.89
5	Medical	Tumor	512 × 512	64 × 64	37.88	0.77	0.97	20.62
6	Lena	Logo_5	64 × 64	8 × 8	26.98	0.81	0.90	10

Figure 6 Performance of proposed algorithm for different gain factors (see online version for colours)

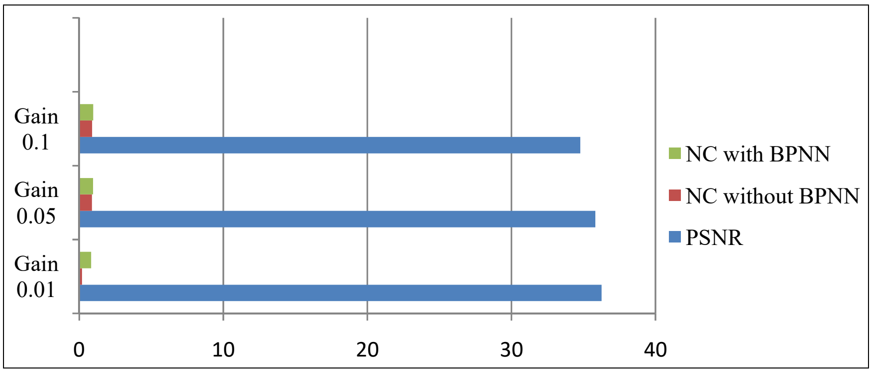


Figure 7 Performance of proposed algorithm for different cover and watermark image at gain 0.1 (see online version for colours)

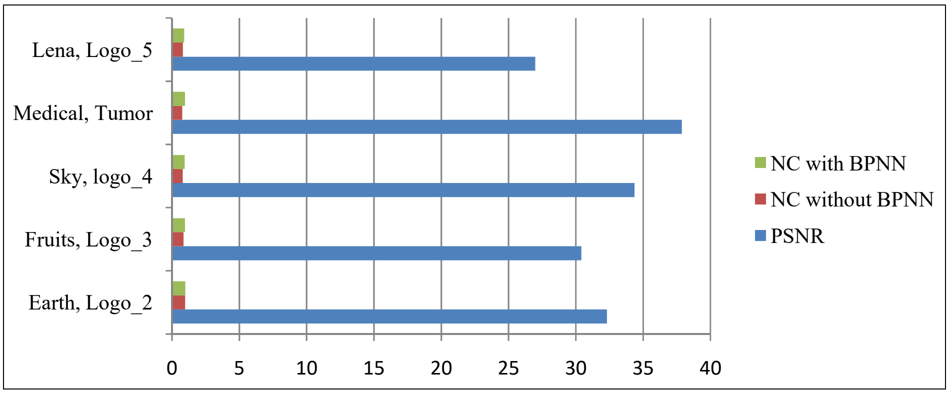


Figure 8 Performance of proposed algorithm against different signal processing attacks at gain 0.1 (see online version for colours)

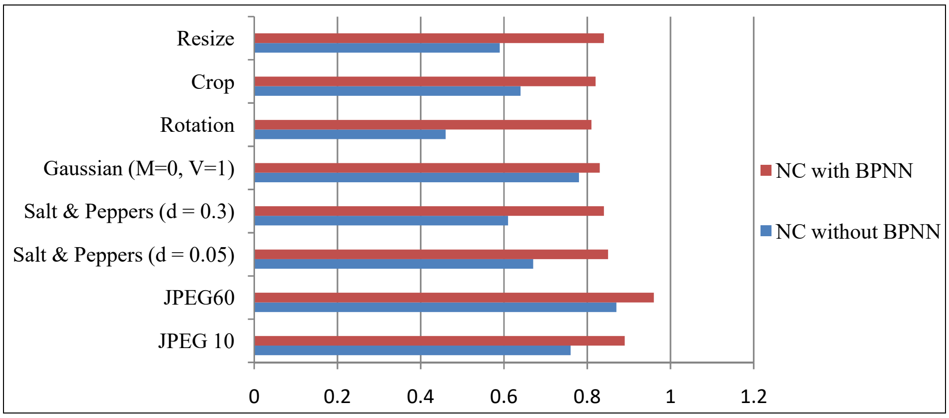


Figure 9 Performance of proposed algorithm compared with existing methods (see online version for colours)

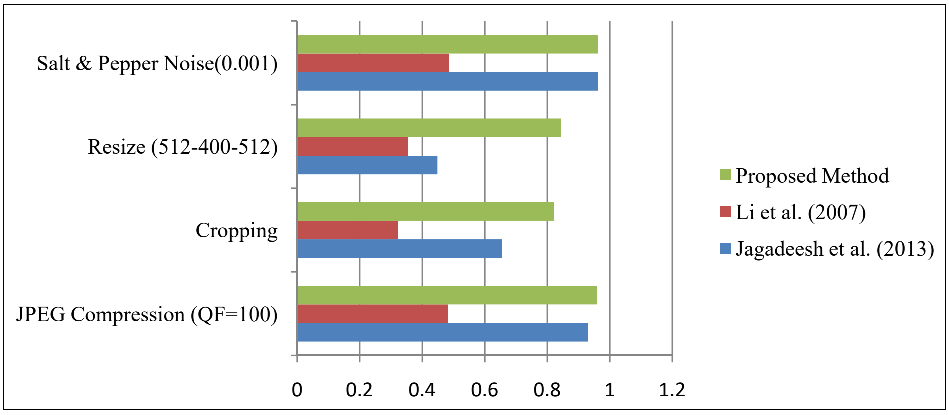


Table 3 shows the performance of the proposed method against different attacks. All the considered attacks are applied to watermarked image created from cover peppers image and logo image at gain factor = 0.1. Without BPNN, the highest NC value has been obtained against JPEG compression (QF = 60). It is 0.87. However, the lowest NC is 0.46 against rotation attacks. With BPNN, all the NC values are above 0.8 for different attacks. The highest NC value has been obtained against JPEG compression (QF = 60). It is 0.96. However, the lowest NC is 0.81 against Rotation attacks. Hence, the NC performance of the proposed method has been improved up to 43.21% with BPNN. Table 4 provides the performance comparison with the existing methods (Jagadeesh et al., 2013; Li et al., 2007). In this table, the maximum NC value with proposed method has been obtained as 0.9634 against 0.4861 and 0.9634 and obtained by the existing method in Jagadeesh et al. (2013) and Li et al. (2007) respectively. Overall, the proposed method is better to that of the existing methods (Jagadeesh et al., 2013; Li et al., 2007).

Table 3 NC performance of the proposed method for different attacks at gain = 0.1

SN	*Attack*	*NC (using DWT, SVD)*	*NC (using DWT, SVD, BPNN)*	*Improvements in NC values (%)*
1	JPEG 10	0.76	0.89	14.61
2	JPEG 30	0.85	0.96	11.46
3	JPEG 60	0.87	0.96	9.38
4	Salt and peppers (density = 0.05)	0.67	0.85	21.18
5	Salt and peppers (density = 0.2)	0.62	0.84	27.19
6	Salt and peppers (density = 0.3)	0.61	0.84	27.38
7	Gaussian (mean = 0, variance = 1)	0.63	0.85	25.88
8	Gaussian (mean = 0.2, variance = 1.2)	0.78	0.83	6.02
9	Rotation	0.46	0.81	43.21
10	Crop	0.64	0.82	21.95
11	Resize	0.59	0.84	29.76

Table 4 The comparison results under NC value

Types of attack	*Jagadeesh et al. (2013)*	*Li et al. (2007)*	*Proposed method*
	NC values	*NC values*	*NC values*
JPEG compression (QF = 100)	0.9304	0.4832	0.9599
Cropping	0.6547	0.3223	0.822
Resize (512-400-512)	0.4484	0.3541	0.8439
Salt and pepper noise(0.001)	0.9634	0.4861	0.9634

5 Conclusions and future directions

In this paper, the proposed hybrid watermarking technique based on DWT and SVD has been presented using BPNN. The main limitations of DWT are shift sensitive, poor directional information and lack the phase information. However, use of SVD is expensive computationally and suffers from false positive detection problem. The robustness of the extracted watermark and visual quality of the watermarked image is greatly depends on gain factors, size of the watermark and noise variations. Through extensive experiments, the following conclusions have been drawn:

1. the fusion of DWT and SVD offer better performance in terms of imperceptibility, robustness and capacity as compared to DWT and SVD applied individually
2. to improve the robustness performance of the proposed method, BPNN is applied to the extracted watermark which gives the higher normalised correlation (NC) values compared to without using the BPNN
3. the robustness performance of the proposed method is compared with other reported techniques and it is found that the method is better than the other reported techniques.

Therefore the proposed method may find potential application in prevention of digital document theft/alteration/modification in different social applications.

The inclusions of many techniques were combined to improve the robustness of the watermarks and the quality of the watermarked image which is the prime objective of the research. However, it may have increased the computational complexity to some extent which needs to be investigated separately. We also need to investigate the performance of the proposed method with multiple watermarks which is required in various applications.

We would like to further improve the performance, which will be reported in future communication.

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