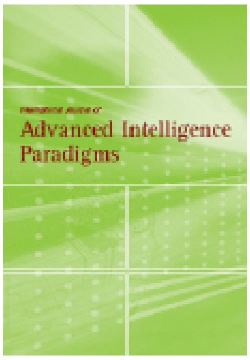

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Robust medical image watermarking technique using integer wavelet transform and shearlet transform with BSVD

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Abstract: There is an increased usage of digital devices in healthcare services for the last few decades because of the advancements made in the medical field. The most appropriate method that is used for the enhancement of security and authentication of medical data is medical image watermarking, which is crucial and used for further diagnosis and reference. This paper focuses on medical image watermarking techniques for the protection and authentication of medical data using hybrid transforms. Several developments on wavelet transform have been proposed in the field of mathematical analysis. One of the recent extensions of wavelet is shearlet transform. A hybrid scheme using integer wavelet transform (IWT) and discrete shearlet transform (DST) is presented in this paper. The images with different textures are examined by this method and resistance is evaluated against various attacks like image processing and geometric attacks. By this proposed method, the results are produced with good transparency and high robustness.

Keywords: medical image watermarking; integer wavelet transform; IWT; discrete shearlet transform; DST; bidiagonal singular value decomposition; BSVD.

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1 Introduction

For the past few years, the medical data of the patient is carried from one doctor to another doctor for better medical care. Transmission of medical Informatics data over a transmission medium is known as telemedicine. The utilisation of telemedicine extends for military services, home monitor, emergency treatment and medical education. When an image is amended or debased during its transmission over an open access network, it leads to aberration in the diagnosis. This may lead to crucial health problems for any individual. Thus, the safe keeping of medical image is essential. These medical images are altered by fiddling during it is transfer to the internet or through any another transmission medium. Several strategies and techniques are present for the safety of medical images. The digital watermarking technique is one of the key solutions to safeguard the medical images (Shih and Zhong, 2016; Sivakannan et al., 2017).

This paper proposed a hybrid watermarking technique which provides security for medical image copyright protection. The method is based on integer wavelet transform (IWT), discrete shearlet transform (DST) and bidiagonal singular value decomposition (BSVD) factorisation. In this work watermark image is inserted in bidiagonal singular values of the cover image. First step is to decompose the cover image by IWT and DST is applied on the low-frequency sub-band of it. From the sub-bands result of DST decomposition, one of them is selected and watermark is directly inserted in bidiagonal singular values of it. The testing is done on various images with different texture characteristics and a wide range of attacks with different parameters are applied on watermarked images. The results of these experiments prove that the proposed method shows high imperceptibility and its robustness against attacks.

In the following of the paper in Section 2, an overview of definition and basic concept of IWT, DST and BSVD is provided. Our IWT-DST-BSVD method will be discussed in Section 3. In Section 4, experimental results will be described and in the last section, conclusions and future studies will be explained.

2 Preliminary

In this section region of interest (ROI) segmentation, IWT, DST and BSVD are described.

2.1 Region of interest segmentation

The medical diagnostic information for various healthcare services is provided by the means of ROI. The ROI must be preserved in order to secure the medical images, such that the watermark embedding is applied only on the remaining portion of the image, which is termed as region of non-interest (RONI). We generally take medical images with multiple ROIs preselected by experts as the input in order to enhance the embedding capacity without distorting the important diagnostic information. The remaining RONIs allow lossy compressions and are used for watermark embedding (Sivakannan et al., 2017).

2.2 Integer wavelet transform

The IWT delineates integers to integers, and enables for perfect inevitability with finite precision arithmetic. The IWT can be done with three arithmetic operations – addition, subtraction and shift (Makbol and Khoo, 2014; Katzenbeisser and Petitcolas, 2000). This characteristic makes it irresistible compared to other discrete wavelet transforms. The

IWTs in Haar wavelet filter can be taken as example (Alattar, 2004; Ahmaderaghi et al., 2014).

$$l_i = \left\lfloor \frac{x_{2i} + x_{2i+1}}{2} \right\rfloor, \quad h_i = x_{2i} - x_{2i+1} \tag{1}$$

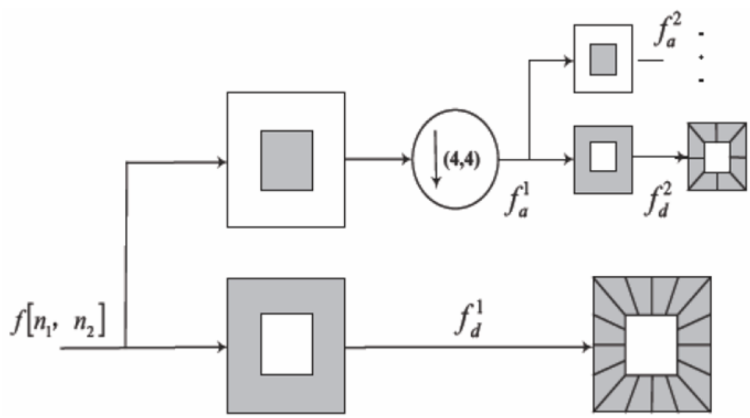
The corresponding inverse transforms are:

$$x_{2i} = l_i + \left\lfloor \frac{h_i + 1}{2} \right\rfloor, \quad x_{2i+1} = l_i - \left\lfloor \frac{h_i}{2} \right\rfloor \tag{2}$$

2.3 DST

The DST is a new discrete multi-scale directional representation with two potentially interesting capabilities for watermarking: using the power of multi-scale methods and capturing the geometry of multidimensional data. The disadvantage of this transform is the increased redundancy (Lim, 2010; Mardanpour and Chahooki, 2016).

Figure 1 Filter bank decomposition of DST



The shearlet transform is implemented by applying the Laplacian pyramid scheme and directional filtering. For an image I, the shearlet transform is a mapping (Xu et al., 2015).

$$I \rightarrow SH\psi I(a, s, x) \tag{3}$$

depending on the scale $a > 0$, the orientation s and the location x. The shearlet transform can be expressed as

$$SH\psi I(a, s, x) = \int I(y)\Psi_{as}(x - y)dy = I \times \Psi_{as}(x) \tag{4}$$

Shearlets are constructed by dilating, shearing and translation which each mother function $\psi \in L_2(R^2)$ is obtained by equation:

$$\psi_{j,k,l}(x) = |\det A|^{\frac{j}{2}} \psi\left(S^k A^j x - l\right): \quad j, k \in Z; l \in Z^2 \tag{5}$$

A and S are invertible 2×2 matrices which represent dilation and geometrical transform as follows

$$A = \begin{pmatrix} a & 0 \\ 0 & \sqrt{a} \end{pmatrix}, \quad S = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix}$$

Hence the DST is defined as below (Zhao et al., 2015):

$$SH\left\{\psi_{j,k,l} = 2^{\frac{3}{2}j}\psi\left(s_k A_{2j} - l\right): j, k \in Z, l \in Z^2\right\} \tag{6}$$

2.4 BSVD

Image processing applications such as image hiding, image compression, noise reduction and image watermarking uses matrix factorisation method called SVD. This decomposition method is used for presenting several watermarking techniques. SVD is often used in hybrid schemes because of their computational complexity. Consider an image A with size $m \times m$, whose SVD is given in the form of $A = USV^T$, where U and V are orthogonal matrices, and $S = diag(\lambda_i)$ is a diagonal matrix of singular values λ_i, $i = 1, \ldots, m$, which are in decreasing order.

Many of the singular values of an image do not change even when there is a little distortion and singular values depict natural algebraic image characteristic, these are the features of SVD that enables them to be used in digital watermarking techniques.

The spectral decomposition that is based on SVD is considered to be BSVD. Both these decompositions provide similar singular values though their computation procedure for generating the singular values is different. The only difference between both the decomposition is the routine in which the singular values are calculated (Shaamala et al., 2011; Gowsika and Sathiyapriya, 2015).

BSVD is considered to be better than SVD in terms of their performance and also in term of the number of keys they provide, where BSVD gives four keys while SVD have two keys.

3 Proposed system

In this paper, medical cover image is separated into ROI and RONI. RONI is taken for watermarking. Different types of methods are there for separating ROI and RONI in MATLAB tool. The few methods are polygonal ROI, ROI based on colour, draggable ellipse, draggable freehand region, etc. In this paper draggable freehand region method is used for separating ROI. IWT and DST are exploited with BSVD spectral decomposition for improving robustness and transparency. RONI image is decomposed IWT into four sub-bands LL, LH, HL and HH. Then DST is applied on low-frequency sub-band LL (Easley et al., 2009). Watermark is embedded directly in bidiagonal singular values resulted from BSVD on the selected sub-band which is outcome of DST decomposition (Ali and Ahn, 2014).

3.1 Watermark embedding algorithm

Steps of embedding watermark into host image are as follows:

1 Initially RONI image (A) is decomposed by IWT. Four sub-bands LL, LH, HL and HH are achieved by decomposing.

2 Low frequency sub-band LL is taken for applying DST. Number of scales for DST is set to 3 and vector of shearlet levels is determined to [0, 1, 1]. So that 21 sub-bands are obtained from DST. So, four sub-bands from first scale, eight sub-bands from second and eight sub-bands from third scale are obtained.

3 Embedding host frequency is selected from sub-band in the first scale and vertical orientation. Then BSVD is applied to the selected sub-band according to equation (7).

$$A = U_A U_B S V_B^T V_A^T \tag{7}$$

U_A, U_B, S, V_A and V_B are obtained, where S is the bidiagonal singular values of the image.

4 Bidiagonal singular values of S is taken for embedding watermark image and then SVD is performed as per below equation (8).

$$S + \alpha W = U_w S_w V_W^T \tag{8}$$

where α stands for the scaling factor.

5 The new modified DST coefficients are evaluated as equation (9).

$$A_{new} = U_A U_B S_w V_B^T V_A^T \tag{9}$$

6 Finally, inverse DST and inverse DWT is performed on A_{new} respectively. So, watermarked image, A_w^*, is achieved.

3.2 Watermark extraction algorithm

1 Four sub-bands LL, LH, HL and HH are achieved by decompose watermarked image using IWT. Then LL sub-band is taken for applying DST as per first step of embedding algorithm.

2 BSVD is applied on the sub-band in the first scale and in the vertical orientation.

$$A_w^* = U_A^* U_B^* S^* V_B^{*T} V_A^{*T} \tag{10}$$

3 D^* is calculated as equation (11):

$$D^* = U_w S^* V_w^T \tag{11}$$

4 Extracted watermark ,W^* taken by inverse embedding formula as per equation (12):

$$W^* = \left(D^* - S\right) / \alpha \tag{12}$$

4 Experimental result

The proposed IWT-DST scheme is implemented using MATLAB. ShearLab 3D is used in the proposed method for DST calculations. Greyscale images hand, knee and human head are taken. Size of all these images is 256×256 pixels. In our experiments, the watermark is a greyscale image, 'patient template', with size of 128×128 pixels. Table 1 shows these images respectively.

Table 1 Medical images with its PSNR and SSIM of its corresponding watermarked images

Cover image	*Extracted watermark image*	*Watermarked image*	*PSNR and SSIM*
			PSNR= 53.28 dB SSIM = 0.9998
			PSNR = 52.21 dB SSIM = 1
			PSNR = 53.75 dB SSIM = 1

The effectiveness of our proposed scheme is shown in terms of transparency and robustness against different attacks and quantified through peak signal-to-noise ratio (PSNR) and normalised cross-correlation (NC) respectively.The degree of visual similarity between watermarked and host image shown in PSNR and is computed as an equation.

$$PSNR = 10\log_{10}\left[\frac{\max(x(i, j))^2}{MSE}\right] \tag{13}$$

where MSE is mean square error and it represents the cumulative error between watermarked image and original image.

Structural similarity (SSIM) is an additional method for similarity comparison between two images and is designed to improve traditional methods like PSNR, which has been proved to be inconsistent with human eye perception. The range of SSIM values are [–1, 1], where 1 is acquired when two image is twin. SSIM is calculated as equation (14) on different windows of an image.

$$SSIM(x, y) = \frac{\left(2\mu_x\mu_y + c_1\right)\left(2\sigma_{xy} + c_2\right)}{\left(\mu_x^2 + \mu_y^2 + c_1\right)\left(\sigma_x^2 + \sigma_y^2 + c_2\right)} \quad (14)$$

Table 1 represent the host images and watermark image. PSNR and SSIM values of all host images is written corresponding to watermarked images which is provided by proposed method. As we can say that proposed method is transparent by seeing all values for imperceptibility requirement are high.

As said before, watermarking method has robustness which is measured by NC and it shows similarity between original watermark and extracted one from watermarked image attacked. It is calculated through equation

$$NC(w, \overline{w}) = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[w(i, j) - \mu_w][\overline{w}(i, j) - \mu_{\overline{w}}]}{\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}[w(i, j) - \mu_w]^2}\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}[w(i, j) - \mu_{\overline{w}}]^2}} \quad (15)$$

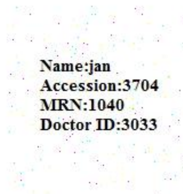
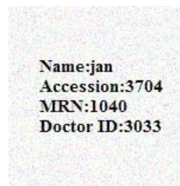
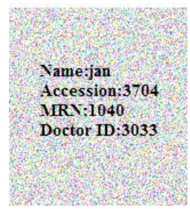
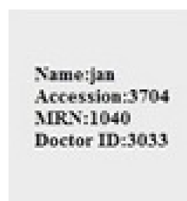
PSNR values mathematical measure of pixel difference between watermarked image and original image. SSIM measures the perceptual difference between watermarked image and original image. Normalised correlation measures the lighting difference between the watermarked image and original image.

Attacks like salt and pepper noise, Gaussian noise, speckle noise and rotation are performed on all of the watermarked images. Robustness of watermarked images has been evaluated using NC. Robustness analysis by NC values of proposed method under different attacks is shown in Table 2.

Table 2 PSNR, SSIM and NC values of different attacks on a various medical images

Attacks	*Hand*	*Knee*	*Human head*
Salt and pepper noise (0.05)	PSNR = 47.53 SSIM = 0.925 NC = 0.9815	PSNR = 46.25 SSIM = 0.95 NC = 0.9918	PSNR = 48.01 SSIM = 0.97 NC = 0.9837
Gaussian noise(0.005)	PSNR = 48.21 SSIM = 0.95 NC = 0.9578	PSNR = 46.34 SSIM = 0.92 NC = 0.9622	PSNR = 48.57 SSIM = 0.97 NC = 0.9578
speckle noise(0.4)	PSNR = 47.91 SSIM = 0.91 NC = 0.9255	PSNR = 45.12 SSIM = 0.89 NC = 0.9818	PSNR = 47.95 SSIM = 0.92 NC = 0.9703
Rotation(45)	PSNR = 46.88 SSIM = 0.89 NC = 0.9149	PSNR = 46.31 SSIM = 0.87 NC = 0.9897	PSNR = 47.31 SSIM = 0.91 NC = 0.9671

Table 3 Extracted watermark images after different attacks on a knee image

Attacks	*Extracted watermark after attack*
Salt and pepper noise (0.05)	
Gaussian noise (0.005)	
speckle noise (0.4)	
Rotation (45)	

5 Conclusions

In this paper medical images are taken for inserting the watermark. For that ROI and RONI are separated from medical image and the watermark embedding is applied only on the RONI. The same hybrid image watermarking technique can be used for other image watermarking applications like satellite image watermarking, military applications, copyright protections, etc. The difference between medical image and other image watermarking technique is there is no need for separating ROI and RONI from other images (ex: satellite images). The most important finding of this study is the blind watermarking method which is done using IWT, DST and a matrix factorisation method called BSVD. Two frequency domain transforms are applied successively to decompose the image leading to make this approach robust against different attacks. As resistance of IWT and DST varies separately, the combination covers weakness of other transforms against some attacks. Thus, the test results exhibit prime transparency and adequate robustness. Our future work will be aimed at standalone implementation of the shearlet system in a cover image and implement the technique in FPGA using HDL coder.

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