A Watermarking Technique for Hyperspectral Images using DWT and Hessenberg Matrix

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Abstract: As the Internet keep growing, copyright protection of the remote sensed image has become more and more important. In this paper, a watermarking technique based on discrete wavelet transform and Hessenberg matrix is proposed. Hyperspectral images consist of large number of bands which contain the captured reflectance spectra values. Wavelet transform is applied on the selected bands of the input hyperspectral image which do not belong to its signature. These selected bands are decomposed into non overlapping blocks of equal size and processed by Hessenberg transform to get its matrix. The largest element of the matrix of each block is used for embedding the encrypted watermark. On receiver side, the watermark is extracted from the watermarked image for protection purpose. To validate the proposed technique, image quality parameters are evaluated on standard hyperspectral datasets. As the experiment result shows, the proposed technique has better security, imperceptibility and thus it can meet the requirements in protecting copyright of the digital remotely sensed image in an effective manner.

Keywords: Hyperspectral Images, DWT, Hessenberg Matrix, PSNR, MSE

1. Introduction: As the Internet technology rapidly develops, it becomes increasingly common to see public data transmission channel, public information publication platform, shared data and easily copying of digital data [1]. All of these factors have helped improve quality of information service, but these also cause the potential data insecurity at the same time [2]. The rapid development of aviation and aerospace technology promote hyperspectral images gradually to become the main source of information for real time applications. [3]. The problem of copyright ownership for the digital remote sensing images and data integrity has become one of the key problems in providing reliable spatial information service [4]. In addition, the digital watermarking technology, as an effective technology for copyright protection, has been studied and used in the fields of image, audio and video [5]. As a result, the digital watermarking technology of the remote sensing images is a feasible solution which can solve copyright protection problem of the hyperspectral images.

The rest of the paper is organized as follows. In Section 2, a brief survey on the recently developed hyperspectral image watermarking techniques have been presented. Section

3 and 4 describe the concepts used and the proposed watermarking technique. Experimental results are reported in Section 5 and conclusions are drawn in Section 6.

2. Related Work:

In this Section, existing watermarking techniques applicable to hyperspectral images is analyzed.

Semi-fragile forensic watermarking technique for remote sensing image is proposed by Serra-Ruiz *et al.* [6]. The authors utilized tree data structure to represent pixels signature and then used quantized concept to embed a watermark into remote sensing image. This embedding is used to detect any significant alteration in the original image. The original hyperspectral image is partitioned into three-dimensional blocks and a tree structured based quantizer is constructed for each block. These trees are modified by using an iterative process until the resulting block satisfies a pre-defined criterion which establishes the embedded mark. The technique can detect forged blocks and can localize them in the image. Ren *et al.* [7] analyzed the characteristics of high-resolution remote sensing images to propose a semi-blind watermarking technique. A key matrix is used to save the matching result whether the highest significant bit of image pixel value is equal with the watermark value or not. In the watermark extraction stage, a key matrix is used to extract the spread spectrum watermark. Melgani *et al.* [8] proposed a discrete cosine transform (DCT) based near-lossless watermarking technique. This is done by embedding the watermark in the middle-frequency range of the DCT coefficients instead of the low-frequency coefficients. The embedding position is determined by a numerical root-finding method, targeted to achieve a user-specified minimum level of robustness against a given ensemble of attacks. Using this, an optimal trade-off can be obtained between visual quality and robustness. Kumari and Rallabandi [9] proposed a modified patchwork-based watermarking (MPW) technique in the spatial domain. This technique is capable of embedding a watermark with minimal modification of the original image pixel values. The MPW watermark embedding process does not create any visual artifacts and is imperceptible. The watermark retrieval process operates with the help of a key and does not require the original image. Jing *et al.* [10] proposed a wavelet transform based robust zero watermarking technique. Their technique constructs two watermarks from the input image. One is constructed from low-frequency wavelet coefficients and the other is constructed from that of the log-polar mapping image of the host image. In this technique, no modification is done in the original image as no data is actually embedded in it. Zhu *et al.* [13] designs an algorithm that protect the remote sensing images using encryption and binary watermark.

The digital watermarking techniques in the above-mentioned studies does not consider the effect of embedding watermark on the signature of the hyperspectral image. In this regard, this paper presents a new digital watermarking algorithm to protect the copyright of remote sensing image which protects the spectral signature of the hyperspectral image. The basic procedure of this algorithm is to select the bands which do not belong to the visible and near infrared spectrum and then to embed the watermark signal into the image by modifying wavelet coefficients using Hessenberg matrix. By doing so, reflectance signature of the input image is not destroyed.

3. Preliminaries

3.1 **Discrete Wavelet Transform**: DWT is identical to a hierarchical subband system, where the subbands are logarithmically spaced in frequency. DWT decomposes the image into L-level dyadic wavelet pyramid. For each level, DWT is applied twice, along rows as well as along columns. The output of this is the production of four equal size subbands which are:

(i) Horizontally and vertically low-pass (LL) subband

(ii) Horizontally low pass and vertically high-pass (LH) subband

(iii) Horizontally high-pass and vertically low-pass (HL) subband

(iv) Horizontally high-pass and vertically high-pass (HH) subband

Let us consider the input image Lena shown in Fig. 1(a) as LL_0 subband. LL_0 subband is decomposed into LL_1, LH_1, HL_1, and HH_1 subbands. At next level, LL_1 is further decomposed into LL_2, LH_2, HL_2, and HH_2 subbands. A two level wavelet decomposition of the image Lena is shown in Fig. 1(b). The decomposition process is repeated until the image is decomposed into required level as shown in Fig. 1(c).

(a) (b) (c)

Fig. 1. DWT pyramid decomposition

3.2 **Hessenberg Matrix**

Hessenberg transform is[11,12] the factorization of a general matrix A by orthogonal similiarity transformations into following form

$$A = QHQ^T \quad (1)$$

Where Q is orthogonal matrix and H is an upper Hesenberg matrix, i.e. $H_{ij} = 0$ whenever $i > j + 1$. It is typically computed by Householder matrices. The Householder matric (P) is an orthogonal matrix as follows.

$$P = (I_n - 2uu^T)/u^T u \quad (2)$$

where u is a non-zerovector in R_n and In is then nxn identity matrix. There are $n - 2$ steps in the overall procedure when A is of size nxn. Therefore, Hessenberg transform is computed as

$$H = (P_1 P_2 \dots\dots\dots\dots P_{n-3} P_{n-2})^{\mathrm{T}} \mathrm{A} (P_1 P_2 \dots\dots\dots\dots P_{n-3} P_{n-2}) \quad (3)$$

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$H = Q^T A Q$ (4)

$A = QHQ^T$ (5)

3.3 Arnold Transform

Encryption is an effective way to protect the contents of digital media. Arnold Transform is very popular and has been widely used as a method to shuffle the secret image. It was proposed by Arnold [14] and is defined by the following equation:

$$\begin{pmatrix} m' \\ n' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} m \\ n \end{pmatrix} \ (mod\ N) \quad (6)$$

where *mod* is modulo operator, (m, n) are the coordinates of the original image pixel, (m', n') are the coordinates of the scrambled image pixel, N is the image size. The transform changes the position of image pixels, and if it is repeated several times, a disorder image is generated.

. This transformation gives more security and robustness to proposed algorithm. There is the periodicity associated with Arnold transform which depends upon the image which is to be encrypted. The purpose of using Arnold i.e. scrambling the secret image is to make it more secure, incase person able to extract the secret image, still won't get the original secret image as it retrieves the scrambled image.

4. Proposed Technique:

This technique consists of watermark embedding algorithm and watermark extraction algorithm.

4.1. Embedding Algorithm

The embedding watermark process using Hessenberg matrix are listed as follows.

Step 1: Convert the watermark image to binary Watermark W. Scramble the binary watermark to encrypt it using Arnold Transform, for improving the security of the watermarking.

Step 2: Read the hyperspectral image.

Step 3: Consider the bands of hyperspectral images as cover image C for embedding watermark which do not belong to the signature of the hyperspectral image.

Step 4: Apply Wavelet transform (DWT) on the cover image Ci , it decompose the image into four bands LL, LH, HL, HH.

Step 5: Consider the LL band and further decompose it into non overlapping blocks with the size of $4x4$.

Step 6: Perform the Hessenberg transform on each block. According to Eq. (1), its upper Hessenberg matrix H is produced.

Step 7: Embed the watermark W into the pixel having highest value $hmax$, by using below code where T is threshold value:

$if(\ W == 1)$

$$h'max = hmax - mod(hmax, T) + 0.75 \times T;$$

$else$

$$h'max = hmax - mod(hmax, T) + 0.25 * T;$$

$endif$

Step 8: Perform inverse Hessenberg transform by using (7) to inverse Hessenberg transform and inverse of DWT to obtain the watermarked image.

$$A' = QH'Q^T \quad (7)$$

4.2. **Extraction Algorithm**

The watermark extracting process of the proposed method is illustrated by Fig. 2. As can be seen from it, the original host image or the watermark image is not required when extracting watermark. So, this proposed method belongs to blind watermarking scheme.

The extraction watermark process is introduced as follows.

Step1: Read the watermarked image and apply DWT.

Step 2: Consider the LL band of watermarked image and decompose it into non overlapping blocks with the size of $4x4$.

Step 3: Perform the Hessenberg transform on each block.

Step 4: Search the pixel element having highest energy of each block and used below equation for extracting watermark.

$if (mod(hmax, T) > 0.5 * T)$

$Watermark = 1;$

$else$

$Watermark = 0;$

$end\ if$

Step 6: Apply Arnold transform on the above extracted watermark.

The above-mentioned steps Step 3-Step 4 are repeated to extract watermark information from all watermarked image blocks.

4.3 Quality Parameters

In this work Peak Signal to Noise Ratio ($PSNR$) is taken as a quality parameter to evaluate the quality of the watermarked image. The $PSNR$ is defined as

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

where MSE is the mean square error and is defined as

$$MSE = \sum_{m=1}^{h} \sum_{n=1}^{w} \frac{(A(m,n) - B(m,n))^2}{h \times w}$$

where $A(m,n)$ is the pixel of watermarked image and $B(m,n)$ is the pixel of cover image, h and w are the height and width of the images, respectively.

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Similarity Index Modulation (SIM) is defined as

$$SIM = \frac{\sum_m \sum_n W(m,\ n)\ \times\ W'(m,n)}{\sum_m \sum_n [W(m,n)]^2}$$

is used evaluate the quality of the extracted secret data by measuring the similarity of the original secret data W and the extracted secret data W'. It is taken as an objective measure in this research work.

Correlation is given by the

$$correlation = \frac{\sum(x-\bar{x}) \times (y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \times \sum(y-\bar{y})^2}}$$

where x is the pixel of cover image, $\bar{x}$ is the mean of the cover image and y is pixel of watermarked image and $\bar{y}$ is the mean of watermarked image.

The larger $PSNR$, the image quality is better. In general, a watermarked image is acceptable by human perception if its PSNR is greater than 30 dB. SIM is generally between 0 to 1. Ideally it should be 1 but upto 0.75 is acceptable. SIM and correlation are used to evaluate the robustness of data hiding technique and $PSNR$ is used for evaluating the imperceptibility of data hiding technique.

5. Experimental Results and Analysis

The Proposed technique is implemented in MATLAB R2019a. The cover images are decomposed by wavelet transform. For this work, different hyperspectral datasets as Salina, Pavia, Pavia University, India-pines etc. are considered. Secret image logo of size 32×32 is shown in Fig. 2(a), and scrambled secret image is shown in Fig. 2(b).

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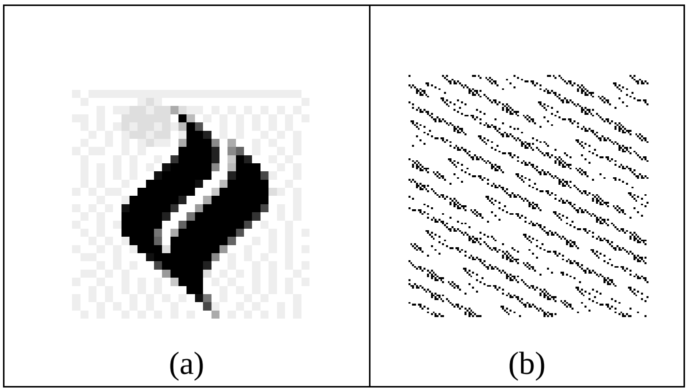

Fig. 2 (a) Secret image **(b)** Scrambled secret image

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Table 1: PSNR, Correlation and SIM for datasets after embedding 32×32 watermark

Name of Dataset	PSNR(dB)	Correlation	SIM
Salina	48.8202	1	1
Indian-pines	60.6239	1	1
Pavia	58.1237	1	1
PaviaU	55.761	1	1
Botswana	61.632	1	1
KSC	81.2405	0.9998	1

From this table, one can infer that visual quality of watermarked hyperspectral images is of good quality. Also Correlation and SIM between original and extracted watermark is one or close to one.

6. Conclusions:

In this paper, a DWT and Hessenberg matrix based watermarking technique applicable to hyperspectral images is proposed. The selected DWT bands are decomposed into non overlapping blocks of equal size. The largest element of the Hessenberg matrix by quantization technique of each block is used for embedding the encrypted watermark. On receiver side, the watermark is extracted from the watermarked image for protection purpose. To validate the proposed technique, image quality parameters are evaluated on standard hyperspectral datasets. As the experiment result shows, the proposed technique has better security, imperceptibility and anti-attack robustness, and thus it can meet the requirements in protecting copyright of the digital remote sensed image in an effective manner**.**

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