A Robust Blind Watermarking Scheme for Ownership Assertion of Multi-band Satellite Images

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Abstract: *Satellite images serve as very reliable sources for crucial information of inaccessible areas which incur high costing in their acquisitions. Hence, they must reside with their rightful owners as their mishandling may lead to serious consequences. A robust blind watermarking scheme for multi-band satellite images is proposed in this paper. Ownership information is embedded into cover image via minimum manipulation of pixel values such that the classification results are not much affected. Homogeneity analysis of the cover image is performed to chalk out homogeneous sites for embedding of copyright information. To further enhance the security of the scheme, random chaotic mapping along with convolutional encoding and viterbi decoding and multiple secret keys (four) has been employed. The robustness of the scheme has been tested against comprehensive set of attacks and evaluated using Normalized Cross Correlation (NCC) and Peak Signal to Noise Ratio (PSNR) metrics. The comparative results with the other existing state of the art approaches confirm the efficacy of the proposed scheme.*

Keywords: *Robust blind watermarking, ownership information, chaotic mapping, convolutional encoding, viterbi decoding, normalized cross correlation, peak signal to noise ratio.*

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1. Introduction

The advancement of technology has paved multiple ways to access world wide information without making much efforts. Geographic Information Systems (GIS) is one such wide spreading technology that has eased capturing and retrieval of information via its various modes. A remote sensing image is one of the primary sources whose information value is very high along with its acquisition cost. Mishandling of such information may lead to serious problems like ownership disputes, revelation of secret information publicly, knowledge about land cover, soil fertility assessments, location of military sites etc. To handle such situations, generates the need of digital watermarking. It is the art of hiding information into the digital signal which may latter be used to verify the authenticity or ownership [1, 8, 17].

Many watermarking schemes have already been proposed in the literature for satellite imagery [3, 5, 11, 13, 14, 15, 16]. A pinned sine transform domain based watermarking scheme separating the pinned and the boundary fields of the cover image has been proposed in [5]. The watermark was embedded into the pinned field exploiting its sensitivity to change of any textural information and localize the malicious tampers with high accuracy. Increasing the level of security by scrambling the cover image and obtaining the level of Wavelet sub-bands depending upon the resolution of the satellite image has been brought up in [11]. Unfortunately, the degree of robustness attained by the above scheme was not very satisfying. Enhancement of robustness against Joint Photographic Experts Group (JPEG) lossy compression and various noises during transmission has been proposed in [13]. It was applicable for all kinds of multispectral and hyperspectral images. The robustness and distortion trade-off was further optimized using the multi objective evolutionary algorithm by designing an appropriate fitness function in [16]. Employing Redundant Discrete Wavelet Transform (RDWT) to watermark images adaptively using a correlation mask has been proposed in [15]. The signatures were distorted to very lesser degree owing to over complete representation of RDWT as compared to normal DWT domain. The vector quantization approach for the remote sensing images, manipulating these trees iteratively to embed the watermark has been proposed in [12]. In [3] the watermark can be detected even in the compressed state of the cover image though a slight compromise in compression efficiency has to be paid for it.

The efficiency of the watermarking scheme increases if it doesn’t require the original cover image for extraction. Such schemes are called as blind schemes. One such DCT based blind watermarking scheme exploiting human visual system sensitivity to embed pseudo-random sequence into the DCT coefficients has been proposed in [10]. Scheme was robust against most of the signal processing techniques and geometric distortions. However, the correlation among image bands was ignored and optimum positioning and length of watermark needed to be analyzed further. Setting threshold measures for embedding of secret information into the wavelet sub bands has been proposed in [6]. Pseudorandomly selecting pixel pairs for embedding of secret watermark bits has been the baseline idea of the patchwork based watermarking scheme [2]. However, it produces visualartifacts which is eradicated by a new version of the scheme known as Modified Patch Work (MPW) [7] based scheme. It selected pixel pairs with the same DN values in the vicinity of each other. The watermark bit sequence and its corresponding one's complement were embedded into the selected pixel pairs based on a secret key. Although, various watermarking schemes have been evaluated in [9] but still there is no absolute watermarking scheme in the literature.

The essential requirements for watermarking of satellite image are minimum manipulation of pixel values and topographic mapping. The proposed scheme is an effort towards developing a robust blind watermarking scheme satisfying both above said requirements. The rest of the paper is organized as follows: section 2 explains the proposed watermarking scheme while in section 3 the experimental results with analysis have been presented. Conclusions along with the future scope are mentioned in section 4.

2. The Proposed Approach

The proposed watermarking scheme is applicable to any of multispectral, hyperspectral or ultraspectral images. In the present paper, we have considered multispectral LANDSAT Images (I) of size $P \times Q \times B$, where B signifies the number of bands and P, Q represent width and height of the original image respectively.

2.1. Watermark Encoding

- *Step 1*. Based on a secret key (K_1), select a subset of bands (say 'n') from the available ones (say B) of the cover image, where $n \subseteq B$.
- *Step 2*. Quad tree decomposition based homogeneity analysis of the selected bands is carried out using a user defined threshold value (T_v) kept as secret key (K_2).
- *Step 3*. The copyright information (binary watermark) is encoded using convolution encoding of a user defined fixed rate kept as secret key (K_3). The length of the encoded bit sequence must be equal to the count of the homogeneous blocks (N_b) in the selected bands of the cover image.
- *Step 4*. A random sequence is generated based on secret key (K_4) to select the blocks for embedding of encoded copyright information. Firstly, a random sequence $S=s_0,s_1,s_2.......s_{Nb}$ with length N_b is generated using the chaotic map in [4] as follows:

$$s_{n+1} = 1 + 0.3 \times (s_{n-1} - 1.08) + 379 \times s_n^2 + 1001 \times p_n^2) \bmod 3$$

Here, P_n signifies a chaotic logistic map with initial values s_0,s_1,P_0. The secret key(K4= s_0,s_1,P_0) where $(s_0, s_1) \in (-1.5,1.5)$ $p_0 \in (0,1)$. This generated random sequence ($s_0,s_1,s_2.......s_{Nb}$) is sorted and an ordered index sequence ($I_1,I_2,......I_{Nb}$) is obtained which decides the embedding block positions. The following process is repeated for each of the blocks (Q_k) until all the watermark bits are inserted [14].

1. Compute the average $(G_{Q_k}^{mean})$, minimum $(G_{Q_k}^{\min})$ and maximum $(G_{Q_k}^{\max})$ pixel value in each block Q_k.
2. Classify the block pixels into one of the two categories: low(P_L) and high(P_H) intensity classes respectively as follows:

$$G_{Q_k}^{(m,n)} \begin{cases} = P_H & if \quad G_{Q_k}^{(m,n)} > G_{Q_k}^{mean} \\ P_L & Otherwise \end{cases} \quad (1)$$

Where, P_H and P_L signifies the high and low intensity classes and $G_{Q_k}^{(m,n)}$ represents the $(m,n)^{th}$ pixel in block Q_k with G as intensity value respectively.

3. Compute mean value of the intensity classes P_L and P_H as Γ_{P_L} and Γ_{P_H}.
4. Define contrast value $C_{Q_k}^v$ of each block as follows:

$$C_{Q_k}^v = \max(\rho, \beta(G_{Q_k}^{\max} - G_{Q_k}^{\min})) \quad (2)$$

Where β is a constant and ρ is the minimal amount by which a pixel value is allowed to be modified.

5. Calculate average value Δ_{Q_k} for each block of original pixel values and store in key (K_5), required at the time of extraction.
6. Select watermark bit (w_k) from the encoded bit sequence and embed as follows:

If w_k=1,

$$G_{Q_k}^{'(m,n)} = \begin{cases} G_{Q_k}^{\max} & if \quad G_{Q_k}^{(m,n)} > \Gamma_{P_H} \\ G_{Q_k}^{mean} & if \quad \Gamma_{P_L} <= G_{Q_k}^{(m,n)} < G_{Q_k}^{mean} \\ G_{Q_k}^{mean} + \rho & otherwise \end{cases} \quad (3)$$

If $w_k = 0$,

$$G'^{(m,n)}_{Q_k} = \begin{cases} G^{\min}_{Q_k} & \text{if} \quad G^{(m,n)}_{Q_k} < \Gamma_{P_L} \\ G^{mean}_{Q_k} & \text{if} \quad \Gamma_{P_L} <= G^{(m,n)}_{Q_k} < \Gamma_{P_H} \\ G^{(m,n)}_{Q_k} - \rho & \text{otherwise} \end{cases} \qquad (4)$$

Where $G'^{(m,n)}_{Q_k}$ and $G^{(m,n)}_{Q_k}$ are the modified and original pixel values in each block (Q_k) and ρ is a random value selected between 0 and $C^{v}_{Q_k}$.

7. The modified block is then placed in its corresponding position in the cover image.

This process generates the final watermarked image using multiple (5) secret keys.

2.2. Watermark Decoding

The extraction process is blind and requires only four secret keys, known only to the authentic owner. The details of the steps are described as follows:

- *Step 1*. Based on secret key K_1, select the subset of bands from all the available bands of the suspected watermarked image.
- *Step 2*. Using secret key K_2, perform homogeneity analysis of the selected bands of the watermarked image (possibly distorted version of the watermarked).
- *Step 3*. Based on the secret key K_4, select 2×2 sized homogeneous blocks in the same order as at the time of embedding.
- *Step 4*. Compare average values of the blocks to extract the watermark bit as follows:

$$w_k = \begin{cases} 1 & \text{if} \quad \Delta Q'_k > \Delta Q_k \\ 0 & \text{otherwise} \end{cases} \qquad (5)$$

where, $\Delta_{Q'_k}$ and Δ_{Q_k} are the mean of the corresponding blocks in the watermarked and the original cover images fetched from secret key K_5.

The above process is repeated for all the selected 2×2 blocks to extract all the watermark bits.

- *Step 5*. Based on secret key K_3, decode the extracted watermark bits using viterbi decoding to build actual copyright information (Extracted watermark).

3. Experimental Results and Analysis

In order to judge the performance of the proposed scheme, simulation is done on several satellite data sets and watermarks using MATLAB 10. Three of these LANDSAT multispectral satellite images and copyright logos along with the corresponding watermarked images are shown in Figure 1. The values of the constants determined from a large number of experiments are as follows: threshold value was found to be 10.2, $\rho = 3$, $\beta = 1$ and convolution encoding rate as 0.5.

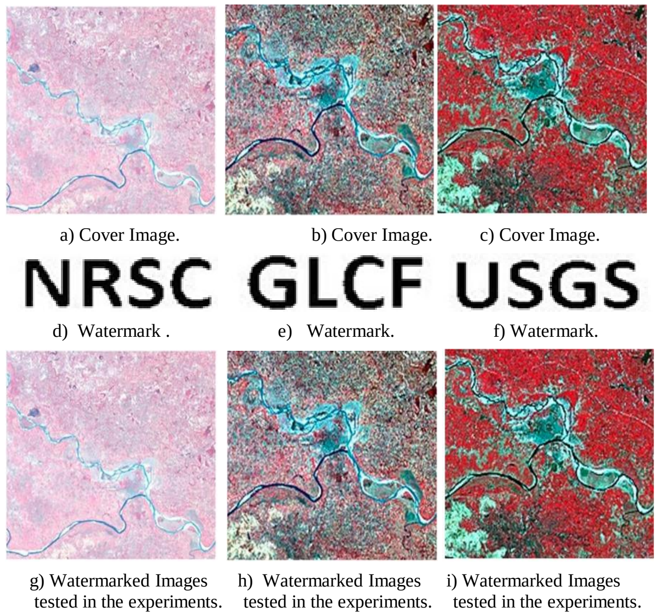


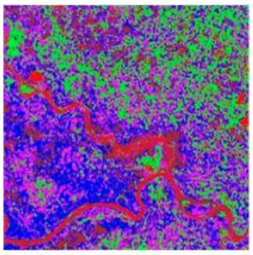
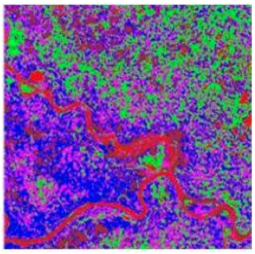
Figure 1. Set of the cover images, watermarks and watermarked images tested in the experiments.

The imperceptibility of the watermarked images is evaluated using Peak-Signal-to-Noise-Ratio (PSNR) metric. High values of PSNR for the proposed methodology (PSNR above 63) indicates its appropriateness as tabulated in Table 1. The scheme also maintains the classification accuracy of the satellite images into various land cover classes even after watermarking. To assess the performance, supervised classification of all the cover test images as well as their corresponding watermarked images has been done taking five land cover classes as shown in Figure 2.

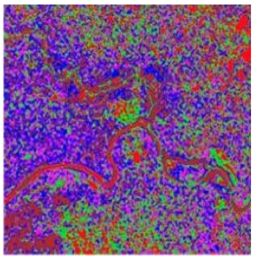
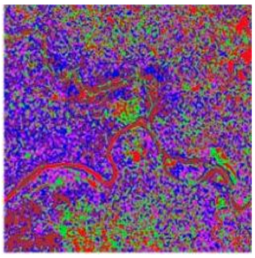
Table 1. Comparative results via evaluation of PSNR metric

Cover image	Proposed	Petitcolas [9]	Serra *et al.* [14]	Qin *et al.* [11]	Ruiz and Megas [12]
2(a)	65.65	62.16	50.12	38.39	42.31
2(b)	66.81	61.08	50.80	38.71	42.43
2(c)	65.47	64.88	50.06	38.94	43.76

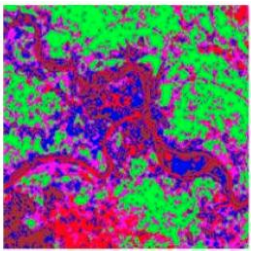
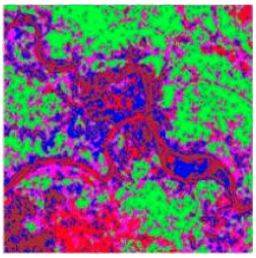
The comparative results with the other existing state of the art approaches are tabulated in Table 2. The classification results are intact as the proposed scheme produces minimal manipulation by embedding into homogeneous blocks producing minimum visual artifacts. The PSNR value varies with two factors considered in the proposed algorithm i.e., the threshold value and the constant value. The variation plots are shown in Figure 3.

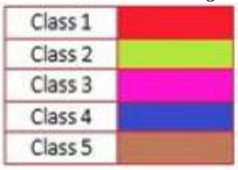
a) Classified Cover Images. b) Classified Watermarked Images.

c) Classified Cover Images. d) Classified Watermarked Images.

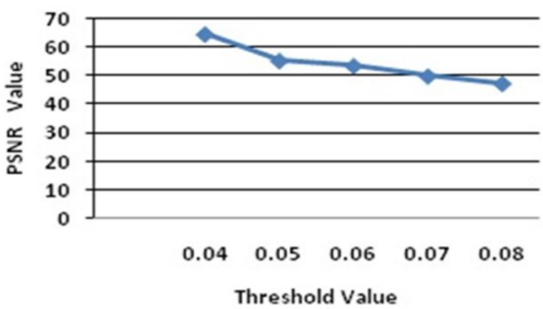



e) Classified Cover Images. f) Classified Watermarked Images.

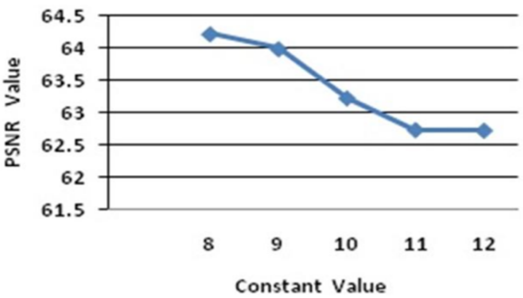


g) Legend used in the experiment.

Figure 2. Set of the classified cover images, classified watermarked images and legend used in the experiment.



a) PSNR vs Threshold value.



b) PSNR vs Constant value.

Figure 3. Variation of PSNR value.

Table 2. Comparative results of supervised classification on pixel count basis for cover test Images and watermarked images.

Cover image	Cover Image	Proposed	Petitcolas [9]	Serra *et al.* [14]	Qin *et al.* [11]	Ruiz and Megas [12]
Class 1	11888	11888	11888	11872	13073	11716
Class 2	59793	59793	59793	59809	58746	58763
Class 3	77450	77450	77450	77450	77426	76374
Class 4	63576	63576	63576	63576	63507	63511
Class 5	26561	26561	26561	26561	26516	27844

Table 3. Attacks on the watermarked images.

Attacks	NCC Value
Weiner Filter(window size 3*3)	1
Salt and Pepper Noise(variance= 0.05)	1
Median Filter(window size 3*3)	1
Speckle Noise(variance= 0.06)	0.84
Gaussian Noise(variance= 0.07)	0.70
JPEG (Quality Factor=80)	1
Circular Average Filter	0.29
Rotation (80 degrees)	1
Cropping	1
Scaled Down (0.75)	1
Contrast Enhancement	1
Histogram Equalization	0.62
Motion Blur	0.50
Average Filter	1

Table 4. Comparison of the proposed scheme with other existing watermarking schemes.

Scheme	Image type	Embedding strategy	PSNR	Robustness
Qin *et al.*[11]	Hyperspectral	Selected signatures	Not reported	median filtering, histogram equalization
Kumari and Rallabandi [7]	Hyperspectral	Selected signatures	Not reported	Median filtering
He *et al.* [4]	RGB	RGB	Not reported	compression, noise
Caldelli *et al* [3]	Grayscale	1 band	40dB	lossy compression
Ho *et* al. [5]	Panchromatic	1 band	55dB	lossy compression,
Piva *et al.* [10]	Grayscale	1 band	45dB	lossy compression
Ruiz and Megas [12]	Hyperspectral	Selected signatures	Not reported	compression, filtering
Ismail *et al.*[6]	Hyperspectral	band by band	Not reported	lossy compression
Serra *et al.* [14]	Panchromatic	1 band	Not reported	enhancement, classification, cropping
Petitcolas [9]	Hyperspectral	16 bands	70dB	lossy compression
Proposed scheme	Multispectral	Selected signatures	65dB	lossy compression, noise, filtering, cropping, rotation, scaled down, enhancement

To validate the robustness of the proposed scheme, various signal processing attacks have been applied on the watermarked images. NCC metric has been calculated to account for the similarity between the extracted watermark and the original watermark with values enlisted in Table 3. The comparative study with the existing approaches based on other parameters are listed in Table 4.

4. Conclusions and Future Scope

A robust blind watermarking scheme exploiting insensitivity of the human visual system has been proposed in the present paper. Adaptively changing the contrast values of the homogeneous sites to embed the copyright information. Security was further strengthened using random chaotic mapping, encoding-decoding scheme along with multiple secret keys. High imperceptibility has been attained as reflected by high PSNR values. The scheme was found to be robust against filtering, noises, rotation, histogram equalization and down scaling attacks, adding to its advantages. In future, focus will be laid on incorporating tamper detection and restoration efficiency in the proposed scheme.

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