Wavelet Transform based Multiple Image Watermarking Technique

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Abstract: In satellite communication the information’s like frequency, Polarization, Data format, Timing information are need to be protected for secure communication. Digital watermarking is the technique which provides secure way of communication in which the secret information or watermark can be transmitted safely. Wavelet Transform is playing an increasingly important role in watermarking due to its good spatial-frequency characteristics, and its wide applications in the image and video coding standards. In this work a novel Hybrid Steerable Pyramid with Discrete Wavelet Transform (SP+DWT) based multiple watermarking is attempted for colour images. In order to increase the robustness of the algorithm Arnold transform and Fibonacci transform based image scrambler is applied to watermarks before embedding in to cover image. The performance of the proposed scheme is validated for various attacks, such as Gaussian noise, Salt & Pepper Noise, Rotation, Translation and Speckle Noise. The proposed method is withstood for all the noise attacks and the performance of the proposed algorithm is measured using Peak Signal to Noise Ratio (PSNR), Normalized Correlation (NC) and Similarity Measure (SM). Pearson Independent component Analysis (ICA) is applied at the receiving end to extract watermarks from the input image. To analyse the inclusion of image scrambler the results of proposed algorithm is compared with same algorithm without image scrambler applied. The performance of proposed technique is also compared with other wavelet transforms like Discrete Wavelet Transform (DWT), Wavelet Packet Transform (WPT) and Integer Wavelet Transform (IWT). Simulation results such as PSNR, NC, SM shows that hybrid SP+DWT based watermarking technique and extraction using Pearson ICA results in high imperceptible, better security and robustness, when compared to DWT, WPT and IWT based watermarking and extraction using Pearson ICA.

Keywords: Wavelet transforms, Wavelet packet transform, Integer wavelet transform, Steerable Pyramid transform, independent component analysis

1. Introduction

The fast growth of innovations in the field of Multimedia and Digital Image Processing Technologies has led to the misuse of various processes such as copying and editing of digital content, which has led to the loss of secure information. This causes the data to be easily encroached upon. A classic example is where the content of an image can be tampered or remodeled, while transmitting over wireless media. Hence the conservation of the data has become a mandatory operation for the application of its use in the field of academics and industry [1]. This is achieved by the watermarking techniques. Digital image watermarking is a recent approach which is used to ensure integrity of medical, military and archival based data. The watermark that is embedded can be of any form namely, audio, text or image. These embedded watermarks are difficult to extract and are generally not
detectable. The embedding of watermark into a digital data produces degradation to the digital data irrespective of the invisibility of the watermark. Reversible watermarking is being used in order to extract the original digital data. This method proves to be superior to cryptography. Keeping all this aspects, in this work a novel wavelet based watermarking algorithm is developed for secure communication in satellite communication [2]. In multiple watermarking schemes more than two watermarks can be embedded and thus watermarking capacity can be improved. RGB and YUV color models are used for image analysis in this work. MATLAB software is used for simulation purpose.

2. Research methods

Initially steerable pyramid transform and discrete wavelet transform is used to decompose the input image in to 9 sub bands in steerable transform output stage and 4 sub bands at DWT output stage. Two of these DWT sub bands can be selected using noise visibility function and two watermarks are embedded in selected sub bands. Before embedding watermark in sub band Arnold transform is applied to watermark1 and Fibonacci transform is applied to watermark2. Then inverse steerable pyramid transform and inverse discrete wavelet transform is applied to concatenate sub bands which provide watermarked image [3].

![Fig.1. Flow chart of SPDWT based watermarking Algorithm](image1)

At the receiver end independent component analysis, Inverse Arnold transform, Inverse Fibonacci transform is applied to retrieve original watermarks which are shown in Fig.2.

2.1 Steerable Pyramid Transform

The Steerable Pyramid is a linear multi-scale, multi-orientation image decomposition that provides
A useful front-end for image-processing and computer vision applications [4]. The block diagram of the steerable pyramid based watermarking algorithm is shown in Fig.1. First, the image passes through high-pass \( H_0 \) and low-pass filter \( L_0 \). The low-pass sub image is then divided into a set of oriented band pass sub images using filters \( B_1, B_2, \ldots, B_K \) and a low pass sub image using filter, where \( k \) is the number of band pass filters [5]. Fig.2 shows decomposition and reconstruction of the steerable pyramid algorithm. In order to avoid aliasing in the band-pass part, the band-pass components are not down sampled. Therefore, the low pass sub band is sampled by a factor of 2 in the horizontal and vertical directions. The recursive construction of a pyramid is achieved by inserting a copy of the shaded portion of the diagram at the location of the solid circle [6]. The set of filters used in this linear decomposition are highly constrained. First of all, to ensure elimination of the aliasing terms, the filter should be band-limited.

\[ \text{Fig.3. Graphical Illustrations of the Steerable Pyramid Transform} \]

In steerable pyramid decomposition, the image is pre processed by a high-pass pre filter and a low-pass pre-filter, to produce low and high sub-bands. The low-pass sub- band is then divided into a set of oriented band-pass sub-bands and a low-pass sub- band. This procedure is continued recursively by sub-sampling the lower low-pass sub-band by a factor of 2 along the rows and columns. If there are \( k \) band-pass filters, then the pyramid is over complete by a factor of \( 4k/3 \).

2.2. Arnold transform

Arnold Transform (AT), proposed by Vladimir Arnold in 1960, is a chaotic map which when applied to a digital image randomizes the original organization of its pixels and the image becomes imperceptible or noisy [7]. However, it has a period \( p \) and iterated \( p \) number of times the original image reappears. The generalized form of Arnold's cat map can be given by the transformation as in equation (1).

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix} = \begin{bmatrix}
2 & 1 \\
1 & 1
\end{bmatrix} \begin{bmatrix}
X \\
Y
\end{bmatrix} \mod (N)
\]

(1)

Where \( x, y \in \{0,1,2,\ldots,N-1\} \) and \( N \) is the size of a digital image

2.3. Fibonacci transform

The Fibonacci sequence is a sequence of integers given by the recurrence relation given by the equation (2).

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix} = \begin{bmatrix}
F_i & F_{i+1} \\
F_{i+2} & F_{i+3}
\end{bmatrix} \begin{bmatrix}
X \\
Y
\end{bmatrix} \mod (N)
\]

(2)
Where \(x, y \in \{0,1,2,\ldots,N-1\}\), \(F_i\) is the \(i^{th}\) term of Fibonacci series and \(N\) is the size of a digital image.

### 2.4. Independent component analysis

The Pearson ICA algorithm is a mutual information-based method for blind separation of statistically independent source signals [8]. Data matrix \(X\) is considered to be a linear combination of statistically independent components and it is written by the equation (3) as

\[
X = AS
\]

Where \(A\) is a linear mixing matrix and the columns of \(S\) contain the independent components of which at most one has Gaussian distribution [9]. The goal of ICA is to find the mixing matrix \(W_d\) such that the output \(\hat{S}\) is an estimate of possibly scaled and permuted and source matrix \(S\) [10]. The de-mixing matrix is defined by the equation (4).

\[
\hat{S} = W_d X
\]

### 2.5. Performance Measures

Performance of proposed algorithm is determined by using three basic parameters namely Peak signal to noise ratio, Normalized correlation and Similarity measure [11]. The same parameters are also used to compare the different watermarking algorithms.

**2.5.1. Peak signal to noise ratio (PSNR):**

PSNR is used to evaluate the quality of the watermarked image and it is defined in equation (5) as

\[
PSNR = 10 \log_{10} \frac{255^2}{\text{MSE}}
\]

Where Mean Square Error (MSE) is given by the equation (6) as

\[
\text{MSE} = \frac{1}{K} \sum_{k=1}^{K} |W_{1k} - W_{2k}|
\]

Where \(W_{1k}\) is original watermark and \(W_{2k}\) is extracted watermark

**2.5.2. Normalized correlation (NC):**

It provides the correlation between original watermark image and extracted watermark image and how these two images look similar [12]. High value of normalized correlation indicate high imperceptible. It is mathematically given in equation (7)

\[
NC = \frac{\sum_{m=0}^{M-1} \sum_{n=0}^{N-1} W_1(m, n) \cdot W_2(m, n)}{\sum_{m=0}^{M-1} \sum_{n=0}^{N-1} W_2^2(m, n)}
\]

Where \(W_1(m, n)\) is the original watermark image and \(W_2(m, n)\) is extracted watermark image at the receiver.
2.5.3 Similarity measure (SM):
This measure provides the quantitative measure of degree of match between two images. Here the matching is between original watermark and extracted watermark [13].

It is mathematically given in equation (8)

\[
SM = \frac{W_1 W_2}{\sqrt{W_1 . W_2}} \tag{8}
\]

Where \( W_1 \) is the original watermark image and \( W_2 \) is extracted watermark image at the receiver.

3. Simulation Results
In this work, the cover image of size 900 x 800 (PET) is taken as input image as shown in Fig.3. Input image which is in RGB is converted into Y, U, V components are shown in Fig.4, Fig.5 and Fig.6. Two watermarks with secret information of size 64 x 64 are considered as shown in Fig.7 and Fig.9. Image scrambling techniques like Arnold transform, Fibonacci transform are applied to watermarks is shown in Fig.8 and Fig.10. 2 scales and 4 orientations steerable pyramid transform and followed by one level decomposition of approximation image using DWT are shown in Fig. 11 and Fig.12, respectively.
Fig. 8. Watermark 1

Fig. 9. Arnold transform of Watermark 1

Fig. 10. Watermark 2

Fig. 11. Fibonacci transform of Watermark 2

Fig. 12. 2 scale 4 orientation Steerable pyramid
Decomposition

Fig. 13. Discrete wavelet transform
Decomposition
First, the Y component of the input image is transformed into steerable pyramid coefficients by using specific values of scales and directions. Edges and high textured area must then be extracted. Indeed, with the steerable pyramid transform, edges and textures are usually well confined to larger magnitude coefficients in the different sub-bands resulting in 2 scales and 4 orientations. 1 approximation and 8 detail coefficients are finally obtained from above mentioned scales and orientations. Next step is to send approximation image to one level wavelet transform to obtain four sub-bands. Now the author selects 2 sub-bands to embed the watermarks. Here in this work, HL2 and LH2 sub-bands are selected to embed watermarks using the Equation (9) and Equation (10).

\[ I'(HL_2) = HL_2(i,j) + E(HL_2) \cdot \alpha \cdot (1 - NVF(i,j)) \cdot W(i,j) + \frac{E(HL_2)}{10} \cdot \alpha \cdot NVF(i,j) \cdot W(i,j) \]  

\[ I'(LH_2) = LH_2(i,j) + E(LH_2) \cdot \alpha \cdot (1 - NVF(i,j)) \cdot W(i,j) + \frac{E(LH_2)}{10} \cdot \alpha \cdot NVF(i,j) \cdot W(i,j) \]  

The range of embedding parameter \( \alpha \) lies between 0 and 1. By trial and error method, the value of \( \alpha \) is chosen as 0.3 to ensure the invisibility and robustness in terms of PSNR and Similarity Measure values, respectively. The watermarked image is obtained by using Inverse DWT first and then Inverse SP. Then the resulting Y component and RGB watermarked image are shown in Fig.14 and Fig.15. Also the watermark robustness is examined with various attacks like Gaussian Noise, Salt & Pepper Noise, Mixed Noise and Translation noise are shown in Fig.16, Fig.17, Fig.18 and Fig.19 respectively.

![Fig.14. Y component of watermarked image](image1)

![Fig.15. Watermarked image](image2)

![Fig.16. Gaussian noise attacked](image3)

![Fig.17. Salt & Pepper noise attacked](image4)
To extract the watermark, blind source separation technique Pearson ICA is proposed and implemented and the watermarks are extracted from various attacks are tabulated in Appendix.3. Hence, the performance of ICA mentioned above is evaluated in terms of Similarity Measure and Normalized Correlation for without scrambling and with scrambling are tabulated in Appendix.1. The results of SPDWT is compared with different wavelet based watermarking algorithms namely Discrete wavelet transform, Wavelet packet transform and Integer wavelet transform and it is tabulated in Appendix.2. From the comparison it is noted that SPDWT produces better PSNR, Similarity Measure as well as Normalized Correlation than DWT, WPT and IWT techniques for all the attacks.

The comparison results of proposed algorithm with other wavelet transform is presented in Fig.20, Fig.21, and Fig.22.

**Fig.20. PSNR plot of wavelet based transform techniques**
4. Conclusion

A Hybrid steerable pyramid transform with discrete wavelet transform is developed for secure communication. Image scrambling methods namely Arnold transform and Fibonacci transform were developed and applied on two watermarks to improve the watermark strength. For watermark extraction Pearson independent component analysis is developed. Developed watermarking algorithm is tested against various noise attacks and algorithm can withstand for all noise attacks. High PSNR, Normalized correlation, Similarity measure shows the high robustness, high imperceptibility of algorithm. Simulation results show that hybrid SPDWT based watermarking technique and extraction using Pearson ICA results in high imperceptible, better security and robustness, when compared to DWT, WPT and IWT with Pearson ICA. This is due to the shift invariant characteristic which results in the existence of redundant data that introduces over complete representation of the input sequence as hybrid SPDWT has linear multi-scale, multi-orientation image decomposition characteristics. Hence, it is concluded that hybrid SPDWT with Pearson ICA is superior to other transforms methods.
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## Appendix

### Appendix 1. Comparison of Performance Measures of SPDWT with and without Image Scrambling Technique

| Input Images               | PSNR(dB)       | Similarity Measure         | Normalized Correlation       |
|----------------------------|----------------|---------------------------|-----------------------------|
|                            | SPDWT without image scrambling | SPDWT with image scrambling | SPDWT without image scrambling | SPDWT with image scrambling | SPDWT without image scrambling | SPDWT with image scrambling |
| Watermarked image          | 48.1294        | 50.6392                   | 0.9721                      | 0.9996                      | 0.9717                      | 0.9912                      |
| Gaussian noise attack      | 45.2831        | 48.4039                   | 0.9528                      | 0.9790                      | 0.9421                      | 0.9798                      |
| Salt & Pepper noise attack | 45.9821        | 49.8293                   | 0.9512                      | 0.9810                      | 0.9574                      | 0.9823                      |
| Rotation noise attack      | 44.3295        | 48.9279                   | 0.9487                      | 0.9772                      | 0.9467                      | 0.9798                      |
| Translation noise attack   | 45.2981        | 48.2109                   | 0.9472                      | 0.9743                      | 0.9426                      | 0.9790                      |
| Mixed Noise attack         | 43.2091        | 47.0923                   | 0.9429                      | 0.9723                      | 0.9309                      | 0.9712                      |
### Appendix 2. Comparison of Performance Measures of DWT/WPT/IWT/SPDWT with Image Scrambling Technique

| Input Images          | DWT          | WPT          | IWT          | SPDWT         |
|-----------------------|--------------|--------------|--------------|---------------|
|                       | PSNR (dB)    | SM           | NC           | PSNR (dB)     | SM           | NC           | PSNR (dB)    | SM           | NC           | PSNR (dB)    | SM           | NC           |
| Watermarked image     | 41.2986      | 0.9178       | 0.9193       | 45.2987       | 0.9337       | 0.9387       | 47.1286      | 0.9617       | 0.9621       | 50.6392      | 0.9996       | 0.9912       |
| Gaussian noise attack | 39.3209      | 0.8852       | 0.8865       | 42.5490       | 0.9198       | 0.9248       | 45.8432      | 0.9535       | 0.9592       | 48.4039      | 0.9790       | 0.9798       |
| Salt & Pepper noise   | 39.1209      | 0.8921       | 0.8912       | 43.7632       | 0.9298       | 0.9284       | 45.3098      | 0.9582       | 0.9597       | 49.8293      | 0.9810       | 0.9823       |
| translation attack    | 39.2908      | 0.8872       | 0.8976       | 42.6392       | 0.9226       | 0.9126       | 44.9965      | 0.9407       | 0.9492       | 48.9279      | 0.9772       | 0.9798       |
| Mixed Noise attack    | 38.2218      | 0.8803       | 0.8817       | 42.1830       | 0.9167       | 0.9102       | 43.2965      | 0.9472       | 0.9412       | 47.0923      | 0.9723       | 0.9712       |
**Appendix-3-Extracted Watermarks from Various Attacks**

| ATTACKS                     | Extracted Watermark 1 by proposed technique | Extracted Watermark 2 by proposed technique |
|-----------------------------|---------------------------------------------|---------------------------------------------|
| Gaussian noise attack       | ![Image](g1)                                | ![Image](g2)                                |
| (Noise density = 0.3)       | ![Image](g3)                                | ![Image](g4)                                |
| Salt & Pepper noise attack  | ![Image](g5)                                | ![Image](g6)                                |
| (Noise density = 0.2)       | ![Image](g7)                                | ![Image](g8)                                |
| Rotation noise attack       | ![Image](g9)                                | ![Image](g10)                               |
| (45˚)                       | ![Image](g11)                               | ![Image](g12)                               |
| Translation noise attack    | ![Image](g13)                               | ![Image](g14)                               |
| (30x30)                     | ![Image](g15)                               | ![Image](g16)                               |
| Mixed Noise attack          | ![Image](g17)                               | ![Image](g18)                               |
| (σ=10, σ = 40%)             | ![Image](g19)                               | ![Image](g20)                               |