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High Capacity Separable Data Hiding Using Repeated Histogram Modification in Integer Wavelet Transform Domain

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Abstract: In this study, we propose a novel high capacity separable data hiding scheme that facilitates one to embed large amounts of data into the digital cover images. A natural image exhibits a property where neighbor pixel values are mostly similar and so, their differences are found to be close or equal to zero. Data is embedded into this difference histogram in a repetitive manner multiple times and thus the proposed scheme provides higher embedding capacity compared to the conventional histogram based techniques. The embedding is performed in the integer wavelet transform domain so as to make the system robust to attacks. Further, the proposed scheme uses minimal side information for restoring the cover image and the secret payload compared to the conventional schemes. Performance comparisons with other existing schemes are provided to demonstrate the superiority of the proposed scheme.

Key words: Separable data hiding, image steganography, histogram based data hiding, integer wavelet transform, superiority

INTRODUCTION

Steganography or data hiding is the process of embedding some data which carries some significant information into a cover media (audio/video files, images). The media camouflaging information is referred to as the cover or host media, the secret information that is hidden and communicated covertly is called as the payload. The host image with the payload is called as the stego-media. Due to the message embedding process, the cover media suffers some distortion, at least statistically though imperceptible, irrespective of the steganographic technique used. At the receiver's end, the secret message is extracted back from the stego image by a reverse process and perhaps the cover/host image could not be restored and is ignored in most applications. Some trivial applications, beyond demanding the fidelity of cover image, stego-imperceptibility and high-payload capacity, also insist on restoring the cover image perfectly. Typical cases include diagnostic medical images, geographic maps, archival images (e.g., calligraphy, painting), military maps, remote sensing images and perhaps any type of images involving legal problems like official documents, E-signatures or legal documents, etc.

The existing reversible data hiding schemes can be categorized into six streams based on their key concerns and method adapted. They are:

- Difference expansion based schemes
- Histogram Shifting based schemes
- Prediction based schemes
- Interpolation based schemes
- Robustness based schemes
- The HVS based schemes (Pei *et al*., 2013; Wu *et al*., 2015; Dragoi and Coltuc, 2014; Ni *et al*., 2008; Lin *et al*., 2008)

Each of these schemes have limitations in the sense of payload capacity, imperceptibility and robustness. The main goal of this study is to present an efficient, yet simple reversible steganography scheme designed for digital images achieving high payload capacity with least distortion and robust to various attacks. The proposed scheme carries out repetitive histogram modifications in integer lifting wavelet transform domain.

MATERIALS AND METHODS

Data embedding algorithm: Input: Clean/Host image C with M-rows and N-columns, Secret payload 'w' in bits, Scan Pattern stego_key_1, Embedding Level (EL) stego_key_2. Output: Stego image $\hat{c}$.

Procedure:

- Step 1: Clean image C undergoes single level integer lifting wavelet transform which results in 4 sub bands (LL, LH, HL, HH) of size M/2×N/2, each: For each sub-band, do Step 2-11

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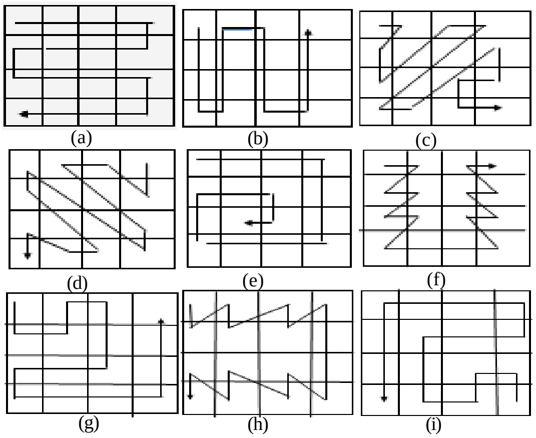

Fig. 1: Nine primitive scan patterns used for embedding: a) Inverse 'S' scan; b) Inverse 'U' scan; c, d) Zigzag scan; e) Spiral scan; f, i) Fractal scans

- Step 2: Scan the sub band according to stego_key_1 (one of the nine patterns shown in Fig. 1), scan ($1 \leq i \in M/2 \times N/2$) and obtain the four, single dimensional pixel sequence $p_1, p_2, \ldots, p_{(M/2)X(N/2)}$
- Step 3: Find the pixel difference over the pixel sequence obtained in step 2 by Eq. 1:

$$\text{pixdiff}(i) = \begin{cases} p_1 \text{ if } i = 1 \\ p_{i-1} - p_i \text{ if } 2 \leq i \leq \frac{M}{2} X \frac{N}{2} \end{cases} \quad (1)$$

Construct a histogram for the pixdiff values.

- Step 4: Select Embedding Level (EL) which is the stego_key_2. EL should be less than 9 to avoid distortion. If EL = 0 implement the Steps 5, 6, 7 and 8, else implement from Step 6,7 and 8, skipping Step 5
- Step 5: Data embedding for EL = 0
- Step 5a: Shift the right bins of b(0) one level rightward as:

$$\text{pixdiff}'_i = \begin{cases} p_1 & \text{if } i = 1 \\ \text{pixdiff}_i & \text{if } \text{pixdiff}_i \leq 0, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ \text{pixdiff}_i + 1 & \text{if } \text{pixdiff}_i > 0, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \end{cases} \quad (2)$$

- Step 5b: Examine $\text{pixdiff}_i = 0$ ($2 \leq i \leq M/2 \times N/2$). Each difference that is 0 can be used to hold one secret bit. If the current processing secret bit w = 0, it is not altered. If w = 1, it is increased by 1. The operation is like:

$$\text{pixdiff}''_i = \begin{cases} p_1 & \text{if } i = 1 \\ \text{pixdiff}'_i + w & \text{if } \text{pixdiff}'_i = 0, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ \text{pixdiff}'_i & \text{if } \text{pixdiff}'_i \neq 0, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \end{cases} \quad (3)$$

- Step 6: Data embedding for EL > 0
- Step 6.a: Shift the right bins of b(EL) EL + 1 levels rightward and shift the left bins of b(-EL) EL levels leftward as:

$$\text{pixdiff}'_i = \begin{cases} p_1 & \text{if } i = 1 \\ \text{pixdiff}_i & \text{if } -EL \leq \text{pixdiff}_i \leq EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ \text{pixdiff}_i + EL + 1 & \text{if } \text{pixdiff}_i > EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ \text{pixdiff}_i - EL & \text{if } \text{pixdiff}_i < -EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \end{cases} \quad (4)$$

- Step 6. b: Examine pixdiff = 0 ($2 \leq i \leq M/2 \times N/1$) in the range of [-EL, EL]. The multilevel data embedding strategy in the integer wavelet transform is described as follows
- Step 6.c: Embed the secret data as:

$$\text{pixdiff}''_i = \begin{cases} p_1 & \text{if } i = 1 \\ \text{pixdiff}'_i & \text{if } -EL < \text{pixdiff}'_i < EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ 2 \times EL + w & \text{if } \text{pixdiff}'_i = EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \\ -2 \times EL - w + 1 & \text{if } \text{pixdiff}'_i = -EL, 2 \leq i \leq \frac{M}{2} \times \frac{N}{2} \end{cases} \quad (5)$$

- Step 6.d: EL is deducted by 1

- Step 6.e: If EL$\neq$0, execute Step 5.2.1 and Step 5.2.2 repeatedly. If EL = 0, execute Eq. (6) and then go to Step 6:

$$pixdiff_i^{''} = \begin{cases} p_1 & \text{if } i=1 \\ pixdiff_i^{'} + w & \text{if } pixdiff_i^{'} = 0, 2 \le i \le \frac{M}{2}\times\frac{N}{2} \\ pixdiff_i^{'} & \text{if } pixdiff_i^{'} \neq 0, 2 \le i \le \frac{M}{2}\times\frac{N}{2} \end{cases} \quad (6)$$

- Step 7: Generate the marked pixels sequence $p'_1, p'_2, \ldots, p'_{M/2\times N/2}$ as:

$$p_i^{'} = \begin{cases} p_1 & \text{if } i=1 \\ p_{i-1} - pixdiff_i^{''} & \text{if } 2 \le i \le \frac{M}{2}\times\frac{N}{2} \end{cases} \quad (7)$$

- Step 8: Rearrange the pixels $p'_1, p'_2, \ldots, p'_{M/2\times N/2}$ in the reverse order of the scan pattern decided by stego_key_1. Apply inverse integer lifting wavelet transform with the four sub-bands as input and construct the output the image $\hat{c}$ with M-rows and N-columns (stego version of C)

An exact reverse process is carried out so as to retrieve the secret and restore the cover image.

RESULTS AND DISCUSSION

In order to demonstrate the performance of the proposed scheme over other existing schemes, various experimental results are shown in this section. Six popularly used gray images are selected as the testing images in the resolution of 512$\times$512 pixels and are shown in Fig. 2.

The proposed algorithm is implemented in MATLAB. In our experiments, the pseudo-random bit generator function is employed to produce the secret message bits and the Peak Signal to Noise Ratio (PSNR) according to Eq. 8 and 9 and structural similarity (SSIM) has been adopted as measurements of image quality. The payload capacity is measured in terms of Bits Per Pixel (BPP):

$$PSNR = 10\times\log_{10}\frac{255^2}{MSE}(dB) \quad (8)$$

Where the MSE is the mean squared error and is measured between the cover image C and the stego image $\hat{c}$, of size M$\times$N as:

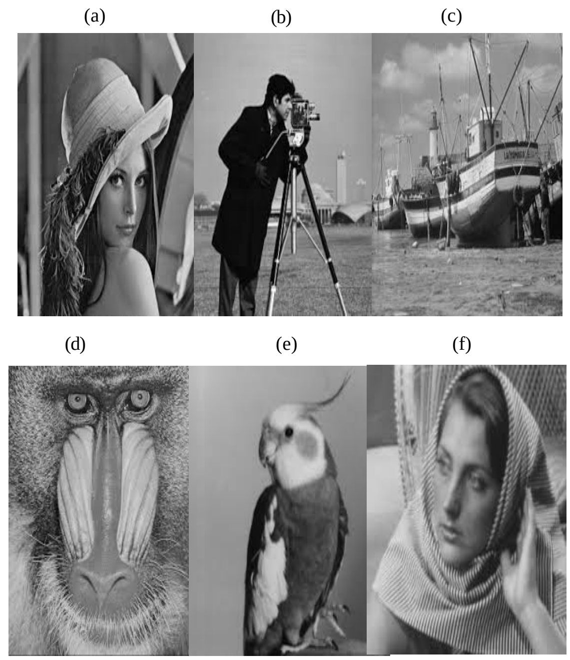

Fig. 2: Test Images; a) Lena image; b) Cameraman image; c) Boat image; d) Baboon image; e) Parrot image; f) Barbara image

$$MSE = \frac{1}{M \times N} \times \sum_{i=1}^{M}\sum_{j=1}^{N}(C(i,j) - \hat{C}(i,j))^2 \quad (9)$$

Our scheme is compared with five state-of-the-art methods proposed by Kim *et al.* (2009), Luo *et al.* (2010), Yang and Tsai (2010), Hu *et al.* (2009) and Zhao *et al.* (2011).

Table 1 shows the experimental results on test images comparing the maximum capacity (maximum number of bits embedded), PSNR-Peak Signal to Noise Ratio and SSIM; Structural Similarity Index Measure, values of the proposed algorithm and others.

All results of capacities, PSNRs and SSIMs are the averages of results obtained by executing with different random bit streams as secrets, 50 times.

Table 1: Performance comparison of the proposed scheme against six existing schemes

Schemes	Metric	Lena image	Cameraman image	Boat image
Kim *et al.* (2009)	Capacity (bits)	48923	47162	42956
	PSNR (dB)	43.2	44.55	42.63
	SSIM	0.9412	0.9046	0.9903
Luo *et al.* (2010)	Capacity (bits)	37138	34786	39522
	PSNR (dB)	45.68	46.83	45.2
	SSIM	0.9746	0.952	0.9966
Yang and Tsai (2010)	Capacity (bits)	44001	44996	45820
	PSNR (dB)	46.1	46.24	46.73
	SSIM	0.9762	0.9543	0.9966
Hu *et al.* (2009)	Capacity (bits)	43327	47295	43946
	PSNR (dB)	44.9	47.75	46.33
	SSIM	0.9739	0.9509	0.996
Zhao *et al.* (2011)	Capacity (bits)	42114	49898	40592
	PSNR (dB)	46.4	46.88	46.1
	SSIM	0.975	0.952	0.9965
Proposed	Capacity (bits)	50903	51681	54855
	PSNR (dB)	48.6	49.5	48.4
	SSIM	0.9768	0.9549	0.9973
Schemes	Metric	Baboon image	Parrot image	Barbara image
Kim *et al.* (2009)	Capacity (bits)	48616	42287	37189
	PSNR (dB)	44.16	44.2	42.85
	SSIM	0.9481	0.954	0.9673
Luo *et al.* (2010)	Capacity (bits)	38271	37372	31433
	PSNR (dB)	46.77	45.31	44.22
	SSIM	0.9779	0.98	0.9863
Yang and Tsai (2010)	Capacity (bits)	42496	43608	45398
	PSNR (dB)	46.03	46.06	46.86
	SSIM	0.9795	0.9819	0.9872
Hu *et al.* (2009)	Capacity (bits)	42255	44460	43890
	PSNR (dB)	47.68	47.6	47.42
	SSIM	0.9776	0.9795	0.9858
Zhao *et al.* (2011)	Capacity (bits)	44227	49635	49383
	PSNR (dB)	46.75	46.76	46.59
	SSIM	0.9782	0.9804	0.9866
Proposed	Capacity (bits)	56934	60681	62442
	PSNR (dB)	49.7	49.3	48.3
	SSIM	0.9803	0.9823	0.9878

CONCLUSION

An efficient reversible data hiding method that performs multiple embedding in the difference histogram in integer wavelet transform domain for image covers is proposed in this paper. This system offers two important advantages, a higher embedding capacity as well as commendable stego picture quality when compared with that of the existing schemes. This scheme can be effectively employed for hiding huge data like patient information, authentication information, annotation or tag information of the patients inside the respective medical image, image authentication systems. The system can be utilised to store the images securely on a semi trusted cloud server.

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