

High Capacity Reversible Data Hiding using IWT

Toshanlal Meenpal

Homi Bhabha National Institute
Mumbai, India
toshan.meenpal@gmail.com

Anup K. Bhattacharjee

Homi Bhabha National Institute
Bhabha Atomic Research Centre
Mumbai, India
anup@barc.gov.in

Abstract— This paper presents a novel lossless data hiding scheme for digital images using integer wavelet transform and threshold embedding technique. Data are embedded into the least two significant bit-plane (LSB) of high frequency CDF (2,2) integer wavelet coefficients whose magnitudes are smaller than a certain predefined threshold. Histogram modification is applied as a preprocessing to prevent overflow/underflow. Experimental results show that this scheme outperforms the prior arts in terms of a higher payload and better PSNR with efficient computations.

Keywords- Lossless data hiding; Histogram; Stego-Image Integer wavelets; histogram modifications.

I. INTRODUCTION

In recent years, the development of multimedia and computer networks has resulted in the widespread use of digital media to replace traditional postal mail. Several researchers have employed data compression technology for efficient and robust media transmission via the Internet. However, the transmission of digital media in an open Internet channel has increased the risk of incurring leaks of sensitive information. Therefore, the protection of sensitive data from attackers in an Internet environment has become an important issue.

Data hiding is an important method for embedding secret data in a meaningful cover medium (such as an image or a video stream) to generate a stego-medium with a small distortion. One of the major requirements of data hiding is that the hidden data must be imperceptible [5]. In order to satisfy the imperceptibility requirement, the quality of stego-image must be improved. In practice, when a sender delivers a stego-image to a receiver, an illegal observer may not perceive the distortion in the transmission and so believes that it is only a common image

Reversible data hiding can provide the extracted data as well as recover the original image at the receiver end without any loss. This property makes it very useful in the areas where image quality is strictly required though the images need the embedded data (watermark) to protect their authenticity/integrity or for some special purposes. The potential applications for this technique cover authentication or content integrity verification, covert communication, and image/video coding (e.g., [1]).

Many existing data hiding algorithms are reversible or lossless (e.g., [2]–[4]). Typical embedding strategies include lossless compression in [2], difference expansion in [4], and histogram modification in [3]. Most of DE-based reversible

data hiding algorithms (e.g.: [4-8]) prefer choosing small pixel pair differences for embedding. For example, Tian [4] first selected the low-frequency coefficients of integer Haar wavelet transform (i.e., image pixel-pair differences) with small magnitude for DE expansion embedding. Alattar [7] extended Tian's pixel-pair difference expansion method using difference expansion of vectors. Kamstra et al. [8] improved Tian's method and selected embeddable differences using a sorting list based on the characteristics of the low-pass image. Small differences tend to occur at the beginning of the sorting list. In addition to the methods developed in integer Haar wavelet transform domain, some researchers also proposed DE expansion methods in other domains. For example, to better use the correlation information of neighboring pixels, Thodi et al. [5] used image prediction rather than integer Haar wavelet transform. They still gave priority to small predicted pixel errors for DE expansion embedding. Thodi et al. further proposed a histogram-based selection scheme for choosing small differences in [6]. The reason of giving priority to small differences for DE expansion embedding is to acquire a high peak-signal-to-noise ratio (PSNR) value of the embedded image. In the aforementioned algorithms, PSNR is used as a metric to evaluate visual quality of watermarked images.

Xuan et al in [9] losslessly compresses one or more than one middle bit-planes to save space for data embedding. The bookkeeping data are also embedded as overhead. Another [10] applies threshold embedding technique to embed data in high frequency IWT coefficients. Lin et al. [11] presented a high-performance reversible data hiding technique based on the block difference histogram of a host image. A delicate lossless data hiding algorithm was proposed by Hsiao et al. [12]. Zeng et al. [13] used adjacent pixel difference and multi-layer embedding techniques on a scan path to obtain a reversible watermarking technique. Yang et al. [14,15] utilized the coefficient-bias algorithm to propose the technique of combinational reversible watermarking in both spatial and frequency domains.

The main contributions of this paper are in enhancement of the data hiding capacity by introducing a new histogram shifting equation and an embedding mechanism. This modification can greatly improve the embedding capacity with graceful degradation of image quality. In addition we have the advantage of selecting a smaller difference coefficient as a threshold value to attain a particular payload requirement.

The rest of this paper is organized as follows. Basic theory involved is explained in section II. Section III describes our reversible data hiding algorithm in detail. Section IV gives the experimental results of our algorithm. In Section V, we draw the conclusion.

II. THEORETICAL FRAMEWORK

The overall scheme is lossless so we use the CDF (Cohen-Daubechies-Faurae) (2,2) integer wavelet transform. It is also adopted by JPEG2000 to obtain the wavelet coefficients for lossless image compression. As per the human visual system human eye is not sensitive to distortions occurring in the high frequency subbands. So we embed data into HL, LH and HH subbands.

Because of the shifting of histograms of high-frequency integer wavelet subbands, it is quite possible that after inverse integer wavelet transform the pixel grayscale value may exceed the upper bound of 255 for an 8-bit image leading to overflow and/or may reduce to value less than the lower bound of 0 for an 8-bit image leading to the problem of underflow which ultimately violates the losslessness requirement. In order to overcome overflow and/or underflow, the histogram modification technique is applied to narrow down the histogram from both sides. The bookkeeping information will be embedded into the cover media together with the information data.

In the aforementioned algorithms, PSNR is used as a metric to evaluate visual quality of watermarked images. However, the PSNR value is essentially the measurement of statistical errors of a modified image rather than a metric for visual perception of the human eye. On the other hand, small differences usually correspond to flat image regions. So alteration to those differences would lead to less artifacts to which the human eye is very sensitive.

III. OUR ALGORITHM

This section gives the details of our algorithm. We first discuss the embedding and extraction formulas, and then, show how to overcome the problem of overflow/underflow problem.

The absolute value of the high frequency coefficient x is compared with T . If $|x| < T$, the coefficient value is quadrupled and the last two LSBs are replaced with the data to be hidden. The resultant coefficient is denoted by x' . If $x \geq T$, then $3T$ will be added to the coefficient, and if $x \leq -T$, the coefficient will be subtracted by $3(T-1)$, and no bit is embedded into this coefficient. These rules are summarized in Formula (1).

$$x' = \begin{cases} 4 \cdot x + b, & \text{if } |x| < T \\ x + 3T, & \text{if } x \geq T \\ x - 3(T - 1), & \text{if } x \leq -T \end{cases} \quad (1)$$

In the data extraction stage, IWT is applied to the marked image to obtain the marked IWT coefficients. For a coefficient, if it is less than $4T$ and larger than $(-4T+3)$, the last two LSBs of this coefficient are the bits embedded into

this coefficient. Otherwise, we proceed to the next coefficient since the current coefficient has no hidden bit in it. In addition to the data extraction, the original cover image should also be possible to be recovered. We can perfectly recover each high frequency coefficient and thus original value can also be recovered by applying Formula (2).

$$x = \begin{cases} \lfloor \frac{x'}{4} \rfloor, & \text{if } 4T > x' > -4T + 3 \\ x' - 3T, & \text{if } x' \geq 4T \\ x' + 3(T - 1) & \text{if } x' \leq -4T + 3 \end{cases} \quad (2)$$

where $\lfloor y \rfloor$ takes the largest integer value that is smaller than y .

The proposed lossless data hiding scheme embeds data into the first level high frequency subbands of images, namely, HL_1 , LH_1 and HH_1 . Preprocessing is performed prior to data embedding to ensure no overflow/underflow will take place. The bookkeeping data of histogram modification (preprocessing) and the payload are to be embedded into the high frequency IWT coefficients. The stego-image carrying hidden data will be obtained after inverse integer wavelet transform. Fig. 1 and 2 are the flowchart of the proposed threshold embedding data hiding and data extraction.

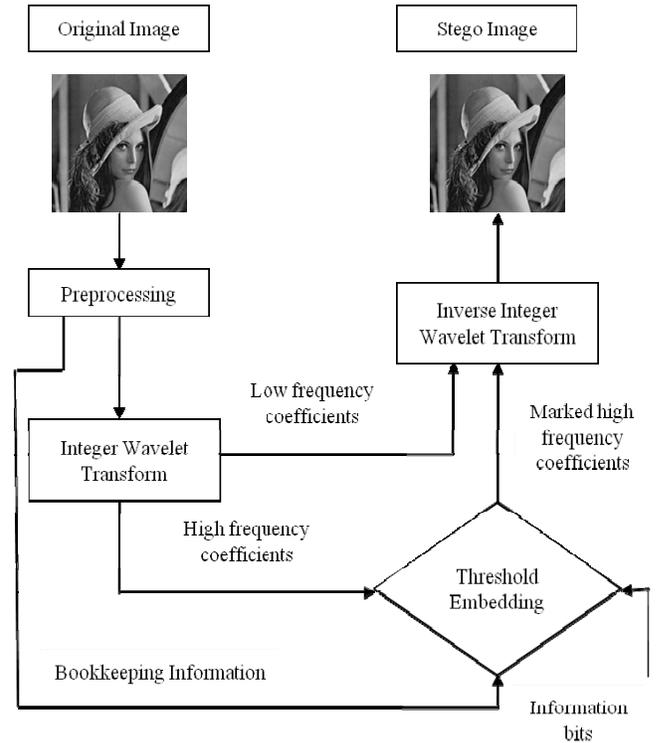


Figure1. Flowchart of the proposed lossless data hiding using threshold embedding.

IV. EXPERIMENTAL RESULTS

We tested our algorithm on different types of images. Some experimental results are given in Fig. 4 and Table II.

According to Table III it is very clear that our algorithm has higher embedding capacity around a specific PSNR value with respect to previous existing schemes.

Our algorithm satisfies the specific payload requirement with a smaller threshold value in comparison to Xuan et al.'s in [10] i.e. the data embedded is denser in the low magnitude difference coefficients. This modification if wisely used with a genuine selection of threshold value can yield better results in terms of payload with less proportionate degradation in PSNR.

Table IV shows the relative percentage as well as payload size of overhead bits embedded as bookkeeping information with respect to the total payload size on various images. We can conclude that the overhead constitutes a very less portion of the total payload which is generally less than 1%.

TABLE II. PAYLOAD V.S. PSNR FOR VARIOUS IMAGES

Images	Payload (bpp)	PSNR (dB)
Lena	1.45	30.56
House	1.5	35.59
Peppers	1.41	30.2
Jetplane	1.42	31.03

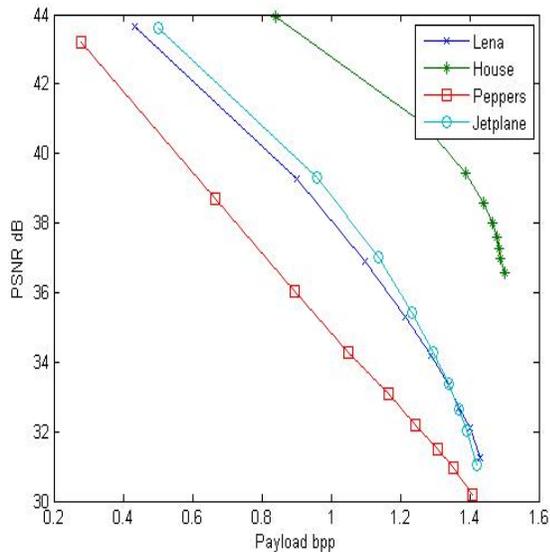


Figure4. Experimental results

Very high payload requirement could also be achieved by increasing the value of threshold. The advantage of the proposed scheme is that it requires less computation and time for high embedding scenarios since the embedding is done in single step only instead of multiple steps in the previous schemes.

Also the PSNR value is essentially the measurement of statistical errors of a modified image rather than a metric for visual perception of the human eye. So in our algorithm to attain a specific payload requirement smaller value of threshold is used and this leads to the less perceptual distortion in the embedded image by visual aspects of human eye and is shown through the help of results.

TABLE III. PAYLOAD SIZE AND PSNR COMPARISON BETWEEN THE PROPOSED PAYLOAD SIZE AND PSNR (AROUND 30 DB)

Methods	Images		
	Lena	Peppers	Jetplane
Lin et al.'s [11]	231,971/ 30.2	268,042/ 30.2	289,877/ 30.1
Hsiao et al.'s [12]	303,700/ 30.00	303,736/ 30.00	286,488/ 30.00
Zeng et al.'s [13]	282,147/ 30.12	317,194/ 29.66	338,492/ 30.08
Yang et al.'s [14]	314,573/ 30.00	317,194/ 29.66	311,404/ 30.71
Yang et al.'s [15]	362,840/ 30.00	333,622/ 29.66	300,608/ 30.71
Proposed method	379,461/ 30.6	369,317/ 30.2	372,513/ 31.03

TABLE IV. OVERHEAD INFORMATION IN TERMS OF SIZE AND PERCENTAGE RELATIVE TO TOTAL BITS EMBEDDED

Images	No. of overhead bits	% relative to total bits embedded
Lena	214	0.09
House	2102	0.63
Peppers	8492	4.86
Jetplane	220	0.09



(a) Original image



(b) 0.45bpp, T=1, PSNR:43.66



(c) 0.9bpp, T=2, PSNR:39.3



(d) 1.4 bpp, T=8, PSNR:32.12



(a) Original image



(b) 0.5bpp, T=1, PSNR:43.6



(c) 0.82bpp, T=2, PSNR:39.3



(d) 1.4bpp, T=8, PSNR:32



(a) Original image



(b) 0.28bpp, T=1, PSNR:43.2



(c) 0.7bpp, T=2, PSNR:38.7



(d) 1.35 bpp, T=8, PSNR:31

Figure5. Experimental results

V. CONCLUSION

In this paper, we have discussed a new algorithm for reversible data hiding. Unlike the previous schemes which aim at embedding single bit per difference coefficient, we embed two bits per coefficient. Under the same threshold value our algorithm yields better payload or embedding capacity with less or equal distortion. The overall process is performed in single step with less computational complexity.

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