and the PSNR are as follows:

$$d = noise\ amplitude,\ rand = \{-1, 0, 1\}$$
$$V_x^d = V_x + d \times rand$$
$$V_y^d = V_y + d \times rand$$
$$PSNR = 20\log_{10}\left(\frac{\mathrm{MAX}(V_{x,y})}{RMSE}\right)$$
$$RMSE = \sqrt{\sum \frac{(V_{x,y} - V_{x,y}^d)^2}{(V_{x,y})^2}}$$

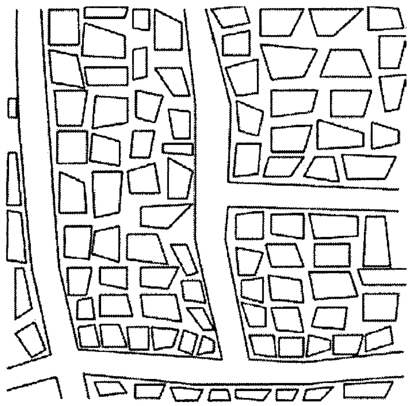

Fig. 2 *Original image*

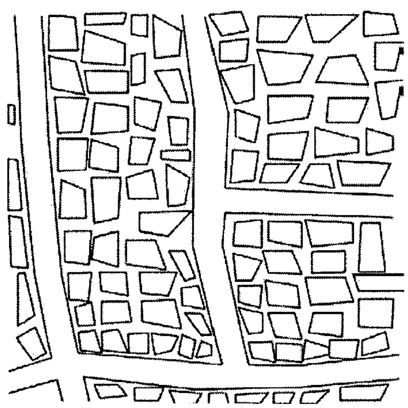

Fig. 3 *Watermarked image*

If the noise is not inserted into the original image, the watermark bits [1 0 0 0 1] are extracted perfectly. Otherwise, Table 1 is shown for $d = 1$. In the Table, the mask size 5×5 is superior to the other two cases. Hence our proposed method is superior to previous work [1].

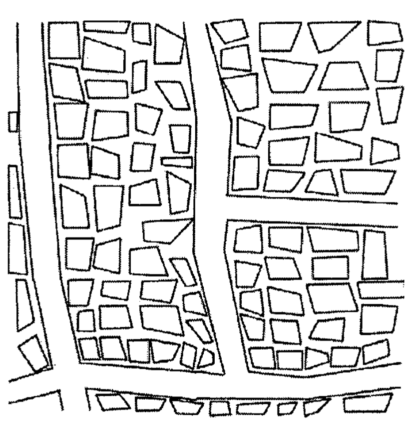

Fig. 4 *Watermarked image attacked by noise*

Table 1: Mask size, percentage of bit reversion and PSNR with noise attack

Mask size	% of bit reversion	PSNR
3×3	43.2	48.9431
4×4	28.8	51.5337
5×5	19.4	50.6527

Conclusion: In this Letter, we generalise the algorithm developed by Sakamoto *et al.* [1]. The proposed algorithm uses the square mask of the arbitrary size rather than of specific size. We show that the proposed method is robust against the noise attack. In the future, we try to obtain the optimal size of the mask according to the image property.

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Distortionless data hiding based on integer wavelet transform

Guorong Xuan, Jiang Zhu, Jidong Chen, Yun Q. Shi, Zhicheng Ni and Wei Su

A novel distortionless image data hiding algorithm based on integer wavelet transform that can invert the stego-image into the original image without any distortion after the hidden data are extracted is proposed. This algorithm hides data into one (or more) middle bit-plane(s) of the integer wavelet transform coefficients in the middle and high frequency subbands. It can embed much more data compared with the existing distortionless data hiding techniques and satisfy the imperceptibility requirement. The image histogram modification is used to prevent greyscales from possible overflowing. Experimental results have demonstrated the validity of the algorithm.

Introduction: By distortionless (or invertible) data hiding, it is meant that the marked media can be inverted into the original media without any distortion after the hidden data are extracted. The technique is expected to have applications in medical and law enforcement fields, where distortion is not allowed owing to legal considerations. Obviously most of current data hiding algorithms are not distortionless. Some distortionless marking techniques have recently been reported in the literature. The first method [1] is carried out in the image spatial domain. Another spatial domain technique was reported in [2]. There also exists a distortionless marking technique in the transform domain [3]. These techniques aim at authentication, instead of data embedding. As a result, the amount of hidden data is quite limited. The first distortionless marking technique suitable for data embedding was presented in [4]. From what is reported in [4], the pay-load ranges from 3000 bits to 24 000 bits for a $512 \times 512 \times 8$ greyscale image on an average basis. This amount of hidden data is still not large enough for, say, some medical applications.

In this Letter we propose a new distortionless marking technique which can embed a larger amount of data. It is carried out in the integer discrete wavelet transform (IDWT) domain. The proposed algorithm is introduced in the following Section.

Proposed distortionless data hiding algorithm: The block diagram of the proposed distortionless data embedding is shown in Fig. 1. Data extraction is an inverse process of the data embedding.

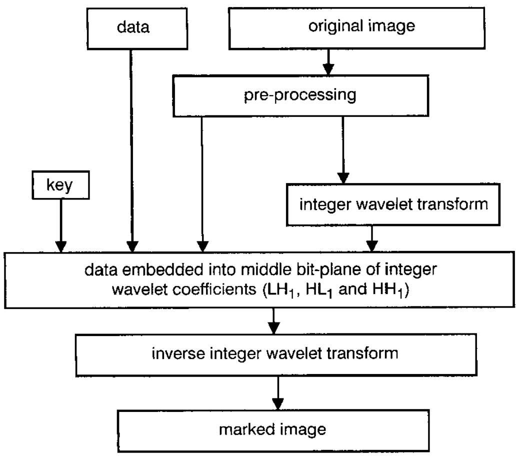


Fig. 1 *Block diagram of distortionless data embedding*

Integer DWT (IDWT): In the following discussion, we consider eight-bit greyscale images and denote the least significant bit-plane by the first bit-plane, the most significant bit-plane, the eighth bit-plane, and so on. Our study on many commonly used greyscale images has shown that binary 0's and 1's are almost equally distributed in the first several 'lower' bit-planes. The bias between 0's and 1's starts to gradually increase in the several 'higher' bit-planes, but not much. This kind of bias indicates redundancy, implying that one may compress bits in a bit-plane or more than one bit-plane so as to leave space to hide data. To achieve a large bias between 0's and 1's, we resort to image transforms. To eliminate more redundancy to embed more data while avoiding round-off error, we propose using second generation wavelet transform, such as IDWT [5], which maps integer to integer and the CDF (2,2) format of which has been adopted by JPEG2000. This technique is based on the lifting scheme [6].

Bit-plane embedding using arithmetic coding. Our study has demonstrated that we can achieve a larger bias between binary 0's and 1's starting from the second bit-plane of the IDWT coefficients than that in the spatial domain. The higher the bit-plane, the larger the bias. However, a change made in a high bit-plane will lead to a larger distortion. To have the marked image perceptually the same as the original image, we choose to hide data in one (or more than one) 'middle' bit-plane(s) in the IDWT domain. To further enhance the visual quality of the marked image, we embed data only in the middle and high frequency subbands, specifically in the LH_1, HL_1 and HH_1 subbands.

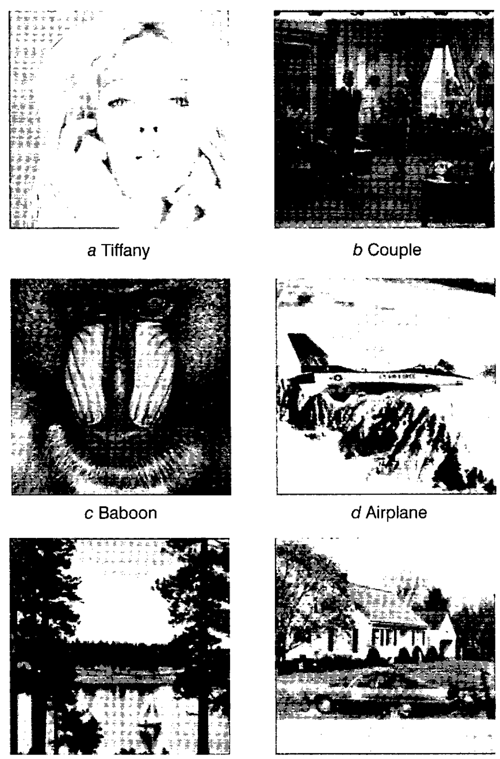
In the chosen bit-plane(s) of the middle and high frequency subbands, the arithmetic coding is chosen to losslessly compress binary 0's and 1's because of its high coding efficiency [7]. Owing to the large bias mentioned above, the difference between the capacity of the subbands in the bit-plane and the amount of the compressed data is able to accommodate the hidden data together with some bookkeeping data.

Secret key. The secret key is used to make the hidden data remain secret even after the algorithm is known to the public.

Preventing possible 'overflow'. It is noted that it is possible for a marked image generated using the above method to have some pixels with *overflowed* greyscale values, meaning that the greyscale values of some pixels in the marked image may exceed the upper bound (255 for an eight-bit greyscale image) and/or the lower bound (0 for an eight-bit greyscale image). This is possibly caused by changes taking place in the chosen bit-plane of the high frequency IDWT coefficients when data are embedded. This problem needs to be resolved in order not to violate the distortionless criterion. For this consideration, the 'pre-processing' is designed and included in the above block diagrams to prevent overflow, i.e. either histogram modification can be used to prevent overflow.

a *b*

Fig. 2 *Lena image*
a Original Lena image
b Marked image (PSNR = 36.64 dB)



a Tiffany *b* Couple
c Baboon *d* Airplane
e Sailboat *f* House

Fig. 3 *Other six images*

Experimental results and conclusion: The proposed distortionless data hiding algorithm has been applied to many typical greyscale images, and has achieved satisfactory results. Here the results and details with Lena image are provided. The Lena image is $512 \times 512 \times 8$. The data are embedded into the fifth bit-plane of the IDWT coefficients in the high frequency subbands LH_1, HL_1 and HH_1. The pre-processing is carried out by the following histogram modification, i.e. the lowest and the highest 16 greyscale values are mapped to greyscale values 15 and 240, respectively. In this way, the overflow is avoided. To recover the original image losslessly late, the data representing the necessary bookkeeping information are also embedded as overhead. The mark signal in the experiment is a binary logo image, equivalent to a binary sequence of 23 040 bits. Hence the hidden data consist of three parts: the mark data, the bookkeeping data, and the losslessly compressed data in the original fifth bit-plane associated with the high frequency subbands. The secret key function used is $y = (k0 + k1 \times x) \bmod s$, in which $k0 = 1030$, $k1 = 289$, $s = 3 \times 256 \times 256$, and x, y are the co-ordinates in the fifth bit-plane. The use of the secret key makes the data hiding positions secret to the third party.

The original and marked Lena images are shown in Fig. 2. It is observed that the imperceptibility requirement is met. Fig. 3 contains a further six marked images. Table 1 shows some experimental results. Note that even though the peak-signal-to-noise-ratio (PSNR) of some marked images against their respective original images is below 30 dB, there is not any annoying structural interference that can be observed. Our study has shown that the not very high PSNR is attributed to the histogram modification in the pre-processing stage. Because there is no annoying artifact in the marked image, and the original image can be distortionlessly recovered from the marked image after the hidden data has been extracted, this should not be a worrying problem.

The proposed invertible data embedding technique is able to embed about 15–94 k bits into a greyscale image of $512 \times 512 \times 8$ imperceptibly, much more than that achieved by existing techniques. The key elements of the technique include the utilisation of: (i) integer wavelet transform that maps integer to integer; (ii) arithmetic coding that losslessly compresses the binary bits in the selected bit-plane of IDWT coefficients in the middle and high frequency subbands; (iii) pre-processing that prevents the possible overflow; (iv) a secret key function that keeps the hidden data secret even after the algorithm is revealed. Consequently, the lossless recovery of original image is achieved.

Table 1: Experimental results

Images ($512 \times 512 \times 8$)	PSNR of marked image (dB)	Pay-load (bits)
Lena	36.64	85 507
Pepper	29.11	69 285
Tiffany	28.91	89 848
Couple	29.83	84 879
Baboon	32.76	14 916
Airplane	36.30	93 981
Sailboat	35.47	44 086
House	36.01	77 726

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Fast feature extraction method for robust face verification

C. Sanderson and K.K. Paliwal

A feature extraction technique for face verification is proposed. It utilises polynomial coefficients derived from 2D discrete cosine transform (DCT) coefficients of neighbouring blocks. Experimental results suggest that the technique is more robust against illumination direction changes than 2D Gabor wavelets, 2D DCT and eigenface methods. Moreover, compared to Gabor wavelets, the proposed technique is over 80 times quicker to compute.

Introduction: Recently there has been much interest in biometric verification systems. A face verification system verifies the claimed identity (a 2 class task) based on images (or a video sequence) of the claimant's face. The claimant is either accepted (classified as a true claimant) or rejected (classified as an impostor).

There are many approaches to facial feature extraction techniques – ranging from the eigenface approach [1], 2D Gabor wavelets [2] to 2D discrete cosine transform (DCT) [3]. PCA derived features have been shown to be sensitive to changes in the illumination direction [4] causing rapid degradation in verification performance. A study by Adini *et al.* [5] shows that the 2D Gabor wavelet derived features are also sensitive to the illumination direction.

As will be shown, 2D DCT-based features are also sensitive to changes in the illumination direction. In this Letter, we introduce the DCT-mod2 feature extraction technique and compare its performance against the 2D DCT, eigenface and 2D Gabor wavelet approaches. We show that the proposed technique is significantly less affected by an illumination direction change.

To keep consistency with matrix notation, pixel locations (and image sizes) are described using row(s) first, then column(s).

2D DCT feature extraction: Here the given face image is analysed on a block by block basis. Given an image block $f(y, x)$, where $y, x = 0, 1, \ldots, N-1$, we decompose it in terms of orthogonal 2D DCT basis functions. The result is an $N \times N$ matrix $C(v, u)$ containing DCT coefficients:

$$C(v, u) = \alpha(v)\alpha(u) \sum_{y=0}^{N-1} \sum_{x=0}^{N-1} f(y, x)\beta(y, x, v, u) \qquad (1)$$

for $v, u = 0, 1, 2, \ldots, N-1$, where

$$\beta(y, x, v, u) = \cos\left[\frac{(2y+1)v\pi}{2N}\right]\cos\left[\frac{(2x+1)u\pi}{2N}\right] \qquad (2)$$

$\alpha(v) = \sqrt{(1/N)}$ for $v = 0$, and $\alpha(v) = \sqrt{(2/N)}$ for $v = 1, 2, \ldots, N-1$. The coefficients are ordered according to a zig-zag pattern, reflecting the amount of information stored [3]. For block located at (b, a), the DCT feature vector is composed of:

$$x = [\, c_0^{(b,a)} \quad c_1^{(b,a)} \quad \cdots \quad c_{M-1}^{(b,a)} \,]^T \qquad (3)$$

where $c_n^{(b,a)}$ denotes the nth DCT coefficient and M is the number of retained coefficients.

Proposed feature extraction method: In speech-based systems, features based on polynomial coefficients (also known as deltas), representing transitional spectral information, have been successfully used to reduce the effects of background noise and channel mismatch [6].

For images, we define the nth horizontal delta coefficient for block located at (b, a) as a first-order orthogonal polynomial coefficient:

$$\Delta^h c_n^{(b,a)} = \frac{\sum_{k=-K}^{K} k h_k c_n^{(b,a+k)}}{\sum_{k=-K}^{K} h_k k^2} \qquad (4)$$

Similarly, we define the nth vertical delta coefficient as:

$$\Delta^v c_n^{(b,a)} = \frac{\sum_{k=-K}^{K} k h_k c_n^{(b+k,a)}}{\sum_{k=-K}^{K} h_k k^2} \qquad (5)$$