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Robust watermarking for scalable image coding-based content adaptation

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Abstract

In scalable image coding-based content adaptation, such as, JPEG 2000, the quality scaling is performed by a quantization process that follows a bit plane discarding model. In this paper we propose a robust blind image watermarking algorithm by incorporating the bit plane discarding model. The new wavelet based binary tree guided rules-based watermarking algorithm is capable to retain the watermarking information for a given number of bit plane being discarded. The experimental simulations confirm the scheme's robustness against JPEG 2000 quality scalability.

1 Introduction

In the state of the art multimedia distribution and consumption scenario, scalable content adaptation coding schemes, such as, JPEG 2000 for image and H.264/SVC for video, offer the solution for seamless multimedia delivery to various end user display devices through the heterogeneous networks. More recently the watermarking robustness to such content adaptation for images, *i.e.*, JPEG 2000 compression, is discussed in the literature [1–8]. To improve the robustness, different approaches have been made, *e.g.*, choosing the coefficients in selected subband [4, 7], using thresholds [1], embedding watermark within wavelet lifting step [6] or using a texture detection algorithm [5]. However, in the algorithmic development most of the algorithms do not consider the effect of JPEG2000 quantization process. To achieve a higher watermarking robustness, in this paper, we propose a new wavelet based blind watermarking algorithm which incorporates JPEG 2000 quantization process, using a bit discarding model. Such an algorithm can easily be combined within the JPEG 2000 pipeline to produce a secured scalable image bit stream.

2 Quality scalable image watermarking

2.1 Scalable coding-based content adaptation

JPEG 2000 uses the Discrete Wavelet Transform (DWT) as its core technology and offers scalable decoding with quality and resolution scalability. The scalable coders encode the image by performing the DWT followed by embedded

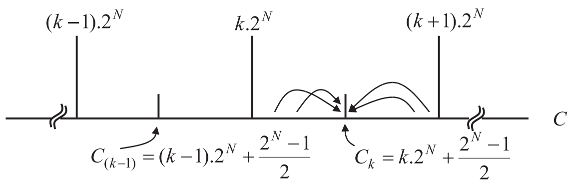


Figure 1: Quantization compression scheme considering N level bit-plane discarding.

quantizing and entropy coding. The coefficient quantization, in its simplest form, can be formulated as follows:

$$C_q = \left\lfloor \frac{C}{Q} \right\rfloor, \tag{1}$$

where C_q is the quantized coefficient, C is the original coefficient and Q is the quantization factor. Embedded quantizers often use $Q = 2^N$, where N is a non negative integer. Such a quantization parameter within downward rounding (*i.e.,* using *floor*), can also be interpreted as bit plane discarding as commonly known within the image coding community.

At the decoder side, a reverse process of the encoding is followed to reconstruct the image. The dequantization process is formulated as follows:

$$\hat{C} = Q.C_q + \left(\frac{Q-1}{2}\right), \tag{2}$$

where $\hat{C}$ is the de-quantized coefficient. In such a quantization scheme, the original coefficient values in the range $k.Q \leq C < (k+1).Q$, where $k \in \pm1, \pm2 \pm 3...$ and $Q = 2^N$ for bit plane wise coding, are mapped to $\hat{C} = C_k$, which is the center value of the concerned region as shown in Fig. 1 and in Eq. (3).

$$C_k = k.2^N + \left(\frac{2^N - 1}{2}\right). \tag{3}$$

2.2 The proposed algorithm

The watermark embedding is performed on the wavelet coefficients generated after forward wavelet transform. The embedding algorithm follows a non uniform quantization based index modulation. The embedding process is divided into three parts: 1) Quantized binary tree formation, 2) Embedding and 3) Extraction and authentication.

Symbol	Binary tree	Watermark Association
Embedded Zero (EZ)	000xxxx	0
Embedded Zero (EZ)	001xxxx	0
Cumulative Zero (CZ)	010xxxx	0
Weak One (WO)	011xxxx	1
Weak Zero (WZ)	100xxxx	0
Cumulative One (CO)	101xxxx	1
Embedded One (EO)	110xxxx	1
Embedded One (EO)	111xxxx	1

Table 1: Tree-based watermarking rules table

2.2.1 Quantized binary tree formation:

The individual coefficients are recursively quantized to form a binary tree. The coefficients to be watermarked, can be selected based on their magnitude, sign, texture information, randomly or any other selection criteria. Firstly the selected coefficient (C) is indexed (b_i) as 0 or 1 using an initial quantization parameter λ:

$$b_i = \left\lfloor \frac{|C|}{\lambda/2^i} \right\rfloor \%2, \;\; i \in 0, 1, 2, 3..., \tag{4}$$

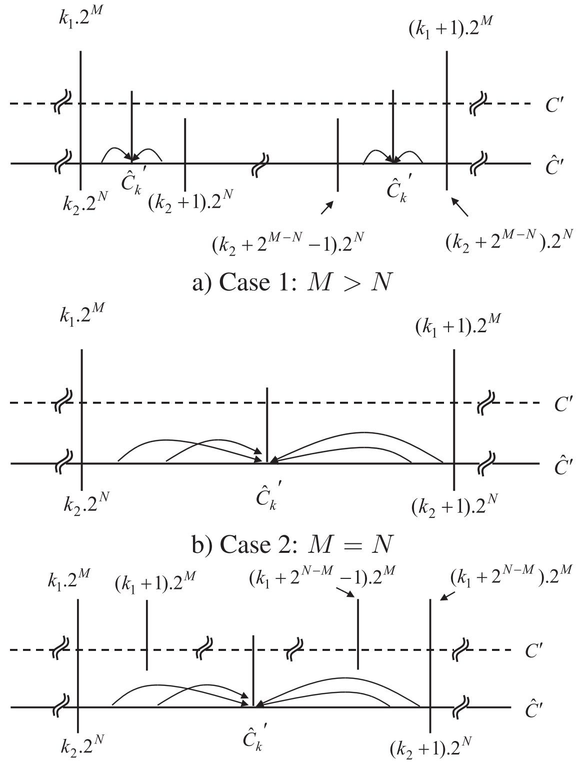
where $\%$ denotes the modulo operation. The coefficient C is then further quantized more precisely within a smaller cluster using a smaller quantization parameter $\lambda/2$ and corresponding index is calculated as: $b_1 = \left\lfloor \frac{|C|}{\lambda/2} \right\rfloor \%2$. The index tree formation is continued recursively by scaling λ value by 2, until $\lambda/2^i \geq 1$. During this tree formation process the *Sign* of the coefficients is preserved separately. To incorporate the bit plane discarding model within the proposed algorithm we restrict initial λ to the integer power of 2. Therefore, the quantization cluster in tree formation can now alternatively be described as a bit plane cluster. Now, based on the calculated index value at various quantization step a binary tree ($b(C)$) of each coefficient is formed as follows:

$$b(C) = (b_0)(b_1)....(b_{i-1})(b_i), \tag{5}$$

where $(b_0), (b_1)...(b_i)$ are binary bits with b_0 as most significant bit (MSB) and b_i as least significant bit (LSB) of the binary tree along with the tree depth of $d = i + 1$. For example if C=142 and initial $\lambda = 32$, the binary tree $b(C)$ will be $b(C) = 001110$.

2.2.2 Embedding:

The binary tree is used to embed the binary watermark information using symbol based embedding rules, by choosing the 3 most significant bits which represent 8 different states corresponding to 6 different symbols (*EZ = Embedded Zero, CZ = Cumulative Zero, WZ = Weak Zero, EO = Embedded One, CO = Cumulative One and WO = Weak One*) to identify the original coefficient's association with a 0 or 1 as shown in Table 1. Based on the input watermark stream, if required, new association is made by altering the chosen 3 most significant bits in the tree to reach the nearest symbol. Assuming the current state of the binary tree is EZ, to embed watermark bit 0 no change in state is required while to embed watermark bit 1, a new value of the binary tree must be assigned associated with either WO, CO or EO. However to minimize the distortion, the nearest state change must occur. Finally the watermarked image is obtained by dequantizing the modified binary tree followed by the inverse transform.



a) Case 1: $M > N$

b) Case 2: $M = N$

c) Case 3: $M < N$

Figure 2: Effect of bit plane discarding in watermark extraction; $\lambda = 2^M$ and N is the number of bit plane being discarded.

2.2.3 Extraction and Authentication:

A universal blind extractor is proposed for the watermark extraction and authentication process. The wavelet coefficients are generated after the forward transform on the test image followed by the tree formation process as in embedding. Based on the recovered tree structure, symbols are regenerated to decide on a 0 or 1 watermark extraction. The extracted watermark is then authenticated by comparing with the original watermark by measuring the Hamming distance (Bit Error Rate).

2.3 The effect of bit plane discarding

Due to the bit plane based clustering in binary tree formation, every value in the binary tree corresponds to the bit planes of the coefficients. Therefore, based on the depth parameter d in the embedding algorithm, the coefficients can retain the watermark even after bit plane discarding. Assuming C' and $\widehat{C}'$ as the watermarked coefficient before and after the bit plane discarding, respectively, we shall examine the effect of N bit plane discarding on every bits within the binary tree during the watermark extraction. Considering initial $\lambda = 2^M$, where M corresponds to the depth of the tree, the bit (b_i) in the binary tree at the extractor can be calculated using Eq. (4):

$$b_i = \left\lfloor \frac{|C'|}{2^M} \right\rfloor \%2 = k_1\%2, \tag{6}$$

where k_1 is the cluster index as shown in Fig. 2. Using the bit plane discarding model in Section 2.1, the watermarked coefficients C' are now quantized and mapped to the center value $\widehat{C}'_k$ within a bit plane cluster with an index value of k_2 as shown in Fig. 2. At this point we consider following three cases to investigate the effect of this quantization and dequantization process:

2.3.1 Case 1 ($M > N$):

In this case the binary tree cluster ($\lambda = 2^M$) is bigger than the bit plane discarding cluster. Hence for any bit plane discarding where $M > N$, $\widehat{C}'_k$ value remains within the binary tree cluster, *i.e.,* $k.2^M \leq (k+1).2^M$ as shown in Fig. 2.a) and

$$b_i = \left\lfloor \frac{|C'|}{2^M} \right\rfloor \%2 = \left\lfloor \frac{|\widehat{C}'|}{2^M} \right\rfloor \%2 = b'_i, \tag{7}$$

where b_i and b'_i represents the bit in binary tree, before and after the bit plane discarding, respectively.

2.3.2 Case 2 ($M = N$):

This case considers the same cluster size in the binary tree and the bit plane discarding, and therefore $\widehat{C}'_k$ remains in the same cluster of the binary tree during the watermark extraction, as shown in Fig. 2.b) and hence, $b_i = b'_i$.

2.3.3 Case 3 ($M < N$):

In this scenario, the number of bit planes being discarded are greater than the depth of the binary tree. Due to the bit plane discarding, any watermarked coefficient (C') in the cluster ($k_2.2^N \leq C' < (k_2{+}1).2^N$) is mapped to the center value C'_k. In terms of the binary tree clustering this range can be defined as ($k_1.2^M \leq C' < (k_1 + 2^{(N-M)}).2^M$) where $(N-M)$ is a positive integer. Hence, during the watermark extraction, the index of the binary tree cluster can be changed and effectively $b_i = b'_i$ is not guaranteed. So far we have explained the effect of bit plane discarding on individual bits of the binary tree. As the algorithm generates the watermark association symbols using the most significant three bits of the binary tree (Table 1), we can define the necessary condition for the coefficients to retain the watermark as follows:

$$d \geq N + 3, \tag{8}$$

where d is the depth of the binary tree and N is the number of bit plane assumed to be discarded.

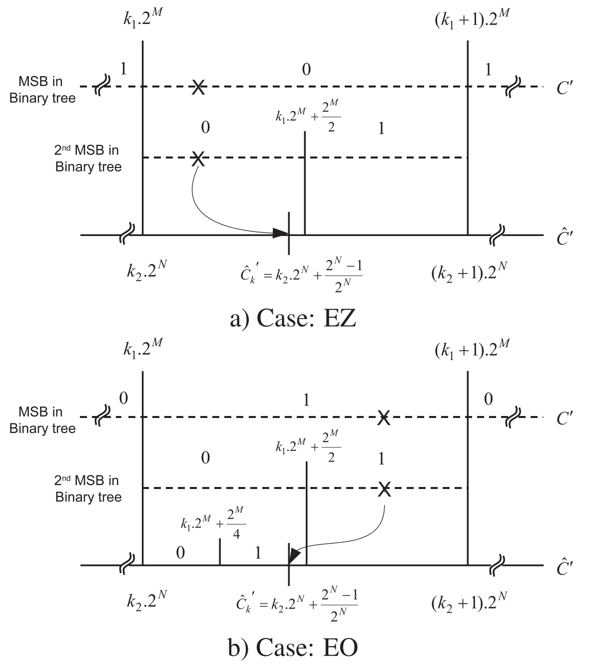


Figure 3: Effect of bit plane discarding in watermark extraction for special case of EZ and EO; $\lambda = 2^M$ and N is the number of bit plane being discarded.

Now considering a scenario, where the embedding modification is done in such a way that all modified coefficients are associated with either EZ and EO and in that case, only most significant two bits are required to be preserved and Eq. (8) becomes:

$$d \geq N + 2. \tag{9}$$

However, in this case, the second most significant bit (MSB) in the binary tree does not need to not be preserved if, MSB is preserved along with the support decision from the third MSB, *i.e.,* EZ and EO are allowed to be extracted as CZ and CO, respectively. Now we will examine the effect of bit plane discarding in such cases when $d = N + 1$.

Case EZ:

In this case, the coefficients (C') are associated to embedded zero (EZ→00x), *i.e.,* $k_1.2^M \leq C' < \left(k_1 + \frac{2^M}{2}\right)$ where $k_1\%2 = 0$, as shown in Fig. 3.a). After N bit plane discarding, C' is modified to the center value $\hat{C}_k = \left(k_2.2^N + \frac{2^N-1}{2}\right)$. For $M = N$ (*i.e.,* $d = N + 1$), k_2 becomes k_1 and therefore:

$$\begin{aligned} \hat{C}_k &= \left(k_2.2^N + \frac{2^N-1}{2}\right) < \left(k_1.2^M + \frac{2^M}{2}\right), \\ \Rightarrow \quad \hat{C}_k &< \left(k_1.2^M + \frac{2^M}{2}\right), \\ \forall \quad k_1.2^M &< \hat{C}_k < \left(k_1.2^M + \frac{2^M}{2}\right). \end{aligned} \tag{10}$$

As a result the second MSB remains 0 in the binary tree. Hence, after $(N + 1)$ bit plane discarding, the coefficient association with EZ remains same and watermark information can be successfully recovered.

Case EO:

Referring Fig. 3.b), for embedded one (EO→11x), the condition for the coefficient association becomes $\left(k_1 + \frac{2^M}{2}\right) \leq C' < (k_1+1).2^M$ where $k_1\%2 = 1$. As in the previous case, after N bit plane discarding, C' is modified to the center value of the corresponding cluster $\hat{C}_k = \left(k_2.2^N + \frac{2^N-1}{2}\right)$. Considering $M = N$, similar to Eq. (10) we can write:

$$k_1.2^M < \hat{C}_k < \left(k_1.2^M + \frac{2^M}{2}\right). \qquad (11)$$

Therefore first two MSB of the binary tree now changed as 11x→10x. At this point, we aim to extract the third MSB (b'), which can be retrieved as:

$$b' = \begin{cases} 0 & : \text{ if } \; k_1.2^M \leq \hat{C}_k < \left(k_1.2^M + \frac{2^M}{4}\right), \\ 1 & : \text{ if } \; \left(k_1.2^M + \frac{2^M}{4}\right) \leq \hat{C}_k < \left(k_1.2^M + \frac{2^M}{2}\right) \end{cases} \qquad (12)$$

Now considering $M = N \Rightarrow \frac{2^N-1}{2} > \frac{2^M}{4}$, Eq. (11) becomes

$$\left(k_1.2^M + \frac{2^M}{4}\right) < \hat{C}_k < \left(k_1.2^M + \frac{2^M}{2}\right). \qquad (13)$$

Combining Eq. (12) and Eq. (13), extracted third MSB becomes $\hat{b} = 1$ and hence 11x→101. Therefore, after $(N+1)$ bit plane discarding, the coefficient association with EO becomes CO and the watermark information can still be successfully extracted.

Combining the above mentioned cases, we can modify Eq. (9) and conclude that, for EZ or EO, the relationship between the embedding depth d and maximum number of bit plane discarding (N) is as follows:

$$d \geq N + 1. \qquad (14)$$

3 Experimental results and discussion

The experimental simulations are grouped into three sets: 1) Verification against the bit plane discarding model, 2) Robustness against JPEG 2000 and 3) Comparison with the existing algorithm. In the experimental sets, a 3 level 9/7 wavelet decomposition is performed using a test data set of 20 images (consists of Kodak test image set and other popular test images). The low frequency subband has been selected to embed binary logo based watermarks. The initial quantization value, λ, is set to 32, resulting in the tree depth of d=6. The embedding distortion is measured here using a new metric, combining the distortion and the data capacity together:

$$\Phi = \frac{\sum_{m=0}^{X-1}\sum_{n=0}^{Y-1}(I(m,n) - I'(m,n))^2}{L}, \qquad (15)$$

where Φ represents embedding distortion rate, I and I' are the original and watermarked image, respectively with dimension $X \times Y$ and L is the number of watermark bits embedded. The robustness is measured by Hamming distance and a lower Hamming distance represents a better robustness.

1) Verification against bit plane discarding:

The proposed watermarking scheme incorporates bit plane discarding model and the experimental verifications for the same are shown in Fig. 4. The y-axis shows the robustness in terms of Hamming distance against the number of bit planes discarded (p) on the x-axis. Different depth (d) values with minimum and maximum embedding distortion rate Φ are chosen to verify our arguments in Eq. (8) and Eq. (14), where the maximum Φ represents all coefficient's association with EZ/EO . For example, at $d = 6$, for Φ_{min}, correct watermark extraction is possible up to $p = 3$ and for Φ_{max}, correct watermark is extracted up to $p = 5$ as shown in the said figures.

2) Robustness against JPEG 2000:

Fig. 5 shows the robustness performance of the proposed watermarking scheme against JPEG 2000 scalable compression. These results compare the robustness for various Φ at a given d. It is evident from the plots that higher depth offers greater robustness to scalable coding-based content adaptation attacks, *e.g.,* JPEG 2000. The results show that more than 35% improvements is achieved when comparing the robustness between two consecutive d.

	Existing algorithm		
	Φ	PSNR	Data capacity (L)
Boat (704×576)	86.40	53.74	2112
Barbara (704×576)	80.64	55.12	2112
Blackboard (704×576)	69.12	56.45	2112
Light House (768×512)	84.48	55.36	2048
	Proposed method		
	Φ	PSNR	Data capacity (L)
Boat (704×576)	84.13	47.43	6336
Barbara (704×576)	81.71	49.13	6336
Blackboard (704×576)	69.12	50.51	6336
Light House (768×512)	82.43	48.78	6144

Table 2: Embedding distortion performance comparison between existing and proposed watermarking method.

3) Comparison with the existing algorithm:

The performance of the proposed algorithm is compared with an existing JPEG 2000 based blind watermarking method [4]. For a fair comparison, considering the embedding distortion and the data capacity together, we set same Φ for both the algorithms. The embedding performance is reported in Table 2 and the robustness against JPEG 2000

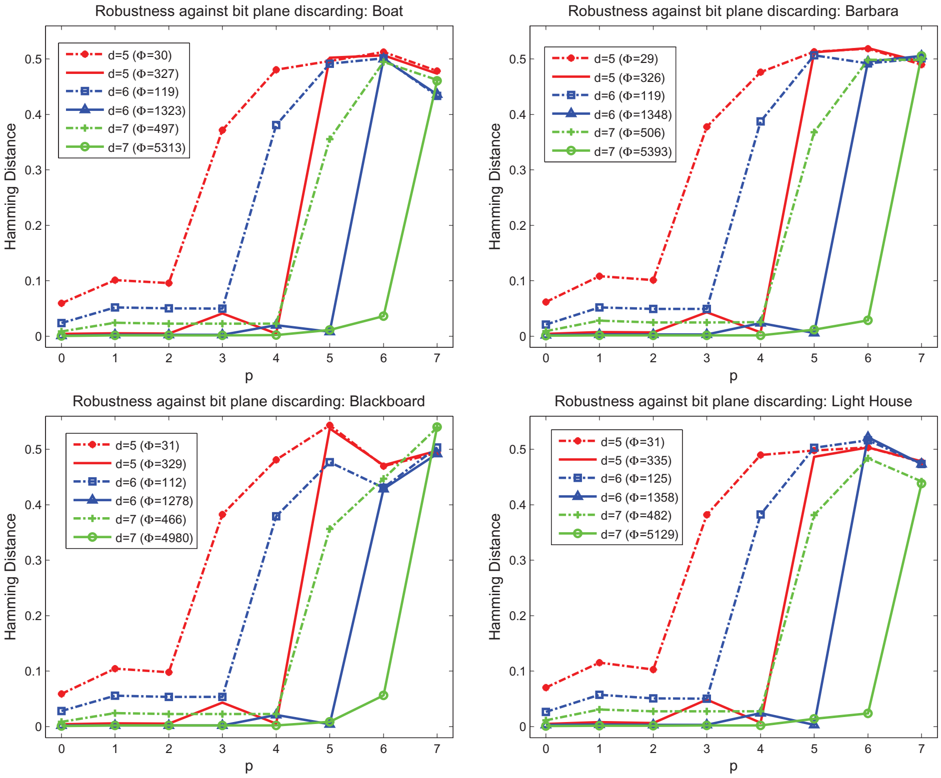


Figure 4: Robustness against discarding of p bit planes for various d at minimum and maximum Φ.

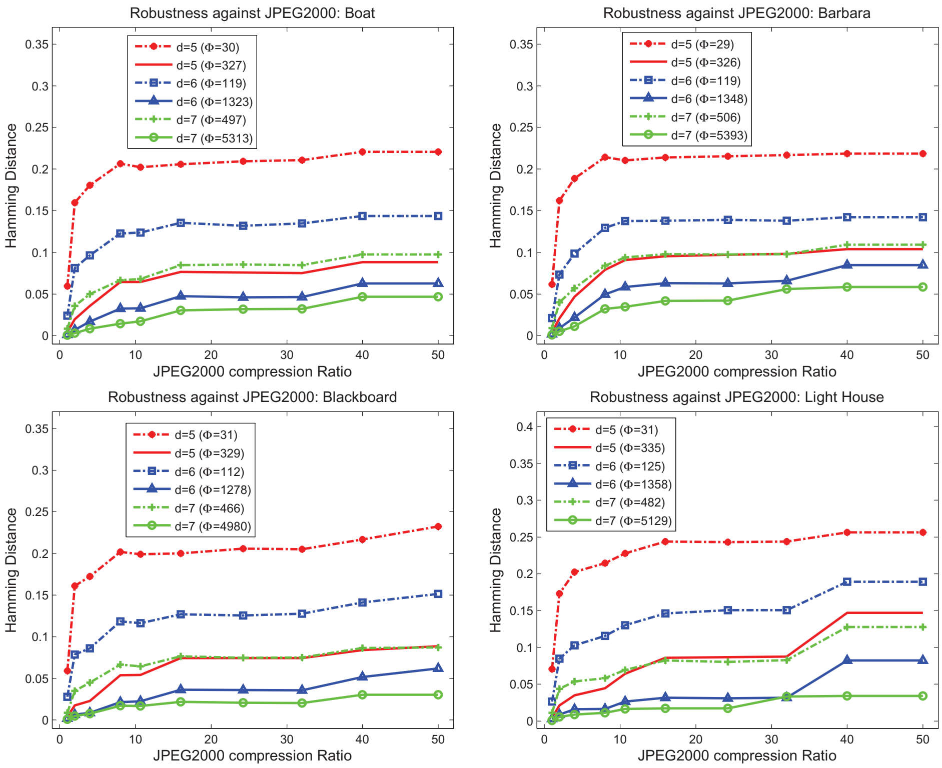


Figure 5: Robustness against JPEG 2000 compression for various d at minimum and maximum Φ.

compression is shown in Fig. 6. In embedding distortion, the existing method shows better PSNR, but the data capacity of the proposed method is reported 3 times higher. In terms of imperceptibility the PSNR is kept well above the noticeable difference in both the cases. On the other hand, despite of higher data capacity the proposed algorithm out-

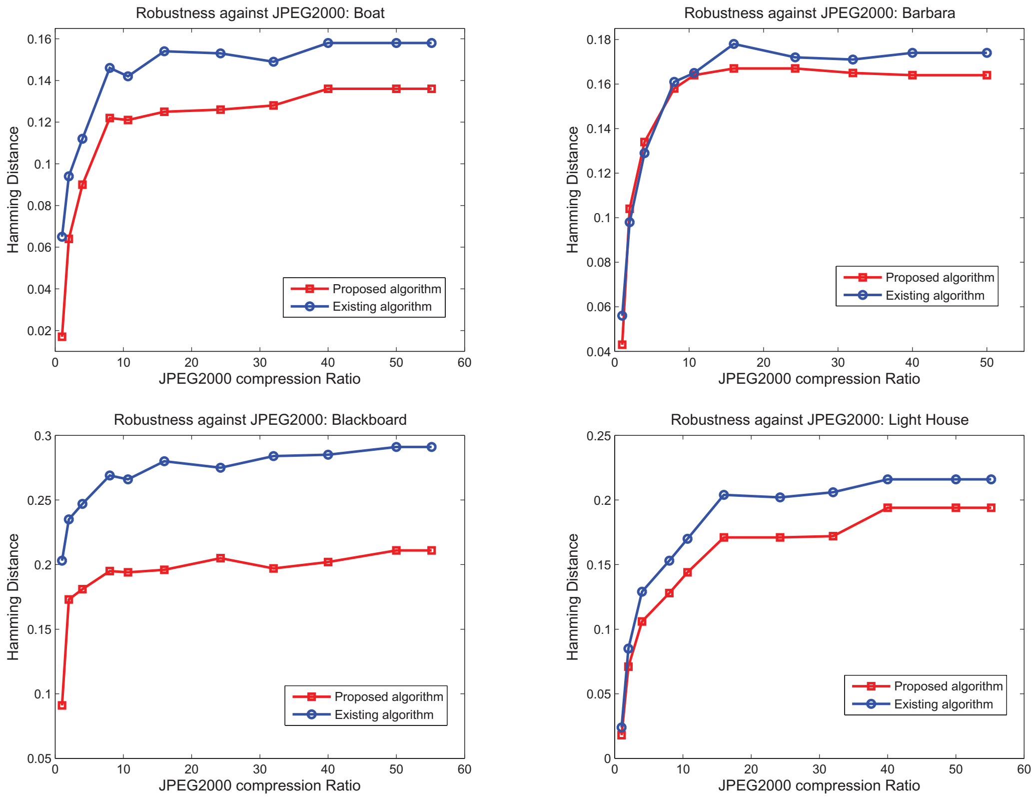


Figure 6: Robustness performance comparison between existing and proposed method against JPEG 2000 compression with same Φ.

performed the existing one in terms of robustness by an average improvement of 25% to 35% at higher compression ratios.

4 Conclusions

In this paper, we proposed a new robust blind watermarking algorithm suitable for scalable image coding-based content adaptation. The algorithm incorporates the JPEG 2000 quantization process which uses a bit plane discarding model. The proposed algorithm is experimentally verified against the bit plane discarding model and the JPEG 2000 quality compression. In comparing the robustness, the new algorithm outperformed the existing JPEG 2000 based blind watermarking scheme.

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