Brief Report

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Article

High Imperceptible Data Hiding Method Based on Combination Theory for AMBTC Compressed Images

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Abstract: The rapid development of digital multimedia has resulted in a massive storm of large-scale data. The data compression method reduces data size and lowers transmission costs. As a result, data-hiding research in the compression domain poses significant challenges to researchers. This work proposes a highly imperceptible data-hiding scheme for a compressed image of Absolute Moment Block Truncation Coding (AMBTC). The combination theory is implemented to ensure the high imperceptibility of the modified compressed images. By only modifying one pixel in a block to embed confidential bits, the experimental findings proven that the proposed method achieved high imperceptibility and high hiding capacity.

Keywords: AMBTC; combination theory; compressed data hiding method; compressed domain; compressed image; data hiding

1. Introduction

A massive storm of large-scale data has come from the accelerated development of digital multimedia. Various applications produce images, audio, and videos daily. The security of critical data and the gigantic volume of data are the two major issues this trend has brought forth. To enhance the confidentiality of data transmission, the sender encrypt the data using conventional cryptographic techniques or imperceptibly transfer data using data-hiding techniques [1–3]. At the same time, the best way to minimize data size and lower transmission costs is to use a data compression technique [4]. Inevitably, data-hiding research in the compression domain presents a immense challenge to academics because it is essential to balance the hiding capacity with compressed image quality.

Data hiding defines as imperceptibly method of hiding confidential data inside other media i.e. digital image, video and audio. An image data hiding scheme categorized into three domains [5] namely spatial domain, frequency domain, and compressed domain. In order to embed confidential data, the spatial domain method is directly modifying the image pixel. It caused the low imperceptibility. On the other side, the frequency domain method hides the confidential data into transformed coefficients. Lastly, the compressed domain method manages the confidential messages in the compressed codes of digital images. Both frequency and compressed domain perform better imperceptibility than spatial domain.

In general, two metrics are used to assess the performance of a data-hiding hiding technique. The first is hiding capacity. Hiding capacity identifies as the quantity of confidential data concealed in a cover media. The second metric is imperceptibility. Imperceptibility defines as the

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imperceptibility defines as the level of image quality after modification. The primary issue in the data hiding research is that the higher the hiding capacity, the lower the imperceptibility.

Along with the big data age, where the volume and variety of data are abundant, compression technology is experiencing advancements. Data compression technology is efficient in data transmission. This is due to the fact that computing is simple and inexpensive. There are several widely used compression methods, including vector quantization (VQ) [6–8], block truncation coding (BTC) [9–12], AMBTC [13], and JPEG compression [14–16]. Beginning by Delp and Mitchell [9] in 1979 which proposed block truncation coding (BTC) for image compression. Then further developed in 1984 by Lema and Mitchell [13] known as absolute moment block truncation coding (AMBTC). AMBTC offers simpler computation than BTC, and performs better image quality.

Due to the benefits of the compression technique, data hiding research is evolving into compression domain data hiding. AMBTC compressed image data hiding method was done by researchers [17–24]. In 2020, Lee et al. [17] presented a reversible data hiding based on Turtle-shell for AMBTC compressed images. Their method provided lower computation complexity and achieved accepted image quality. However, the method does not achieve high hiding capacity because it cannot embed the confidential messages in the complex image.

This research proposes an innovative data hiding scheme for AMBTC compressed images based on the combination theory. Experimental findings show that our proposed scheme achieves high hiding capacity and high image quality, even in complex images.

The remainder of this work is structured as follows. Section 2 provides an overview of the related study. Our proposed data-hiding method is described in Section 3. Section 4 contains the findings of the experiments. Section 5 finally presents the conclusions.

2. Related works

2.1. Absolute Moment Block Truncation Coding (AMBTC)

In 1984, AMBTC was introduced by Lema and Mitchell [13]. The main steps of AMBTC consist of encoding and decoding procedures, and detailed explained as follows: **The Encoding Procedure**

Step 1. Segments the images into a collection of $t \times t$ non-overlapping blocks.

Step 2. Calculates the mean μ and standard deviation α by using (1) and (2), respectively. Assume that p_{ij} is the value of pixel in the block's position *(i, j)*.

$$\mu = \frac{1}{t \times t}\sum_{i=1}^{t}\sum_{j=1}^{t} p_{i,j} \tag{1}$$

$$\alpha = \sqrt{\frac{\sum_{j=1}^{t \times t}\left|p_{ij}{}^{2} - \mu^{2}\right|}{t \times t}} \tag{2}$$

Step 3. Creates the bitmap value $bm = \{m_{ij} | m_{ij} \in \{0,1\}, 1 \le i,j \le t\}$ by using (3):

$$m_{ij} = \begin{cases} 1, if\ p_{ij} \ge \mu \\ 0, if\ p_{ij} < \mu \end{cases} \tag{3}$$

The Decoding Procedure

Step 1. Calculates two quantizers, i.e., high quantizer ***hq*** and low quantizer ***lq*** using (4) and (5), respectively.

$$hq = \mu - \alpha\sqrt{\frac{q}{t \times t - q}} \tag{4}$$

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$$lq = \mu + \alpha\sqrt{\frac{t \times t - q}{q}} \tag{5}$$

Where **q** is the quantity of p_{ij} which greater than or equal to the mean value **μ**.

Step 2. Create the reconstructed block $rm = \{r_{ij} | r_{ij} \in \{hq, lq\}, 1 \leq i, j \leq k\}$ by using (6):

$$rm_{ij} = \begin{cases} hq, if\ m_{ij} = 1 \\ lq, if\ m_{ij} = 0 \end{cases} \tag{6}$$

In order to provide a detailed understanding of the AMBTC compression method, we provide a numerical example as follows. Figure 1 depicts the illustration of AMBTC. First, Figure 1a depicts the original image block size of 4 × 4. Next, we computed the block means μ and standard deviation α, by using (1) and (2) respectively. In this example, the value of μ=78 and α=19. Next, we generate the bitmap in the encoding procedure using (3). The result is shown in Figure 1b. Finally, we calculate the higher and lower quantization levels, *hq* and *lq*, using (4) and (5), respectively. In this example, *hq*=105 and *lq*=62. Finally, the reconstructed image block generated in the decoding procedure using (6) is shown in Figure 1c.

44	61	72	58
74	65	79	62
127	93	75	56
112	117	103	60

(a)

0	0	0	0
0	0	1	0
1	1	0	0
1	1	1	0

(b)

62	62	62	62
62	62	105	105
105	105	62	62
105	105	105	62

(c)

Figure 1. An example of AMBTC Compression Images: (**a**) Original pixel value; (**b**) Bitmap; (**c**) Compressed pixel value.

2.2. The Combination Theory

Wu et al. [25] introduced a novel data-hiding method for binary images using combination theory in 2017. In their method, senders can hides more than one bit of confidential data by modifying one pixel at maximum in one block. The experimental result presented by Wu *et al.*' scheme [25] increases the embedding capacity and reduces the distortion of the modified image.

The main procedure of Wu *et al.*' scheme [25] is as follows:

Step 1. Calculate block maximum payload by (7):

$$b = \lfloor \log_2(u \times v + 1 \rfloor \tag{7}$$

Step 2. Develop a hidden location matrix P as described in [25].

Step 3. Produce the new computed hidden location matrix P' by P⊗Gi.

Then, using Algorithm 1, calculate the total number T(Sr, r =1, 2,..., b) of each bit of confidential data that exists in P'.

Algorithm 1 Confidential Data Calculation

```
FOR p = 1 : u ; q = 1 : v
    IF P'x,y hasSr
        T(Sr) = T(Sr) +1
    END
END
```

Step 4. Calculate the residual value S'r for the total amount of instances of each bit Sr by modulo as in (8)

$$S'_r = T(S_r) mod\ 2, \quad where\ r = 1,2, \dots, b \tag{8}$$

Step 5. Investigate the original confidential data Sr to the feature value S'_r by (9) which consists of S_r such that Sr ≠S'_r

$$S'' = S_r \odot (S_r \oplus S'_r) \tag{9}$$

Step 6. Conceal the confidential data into a block Gi by changing only one pixel of Gi according to Algorithm 2.

Algorithm 2 Confidential Data Embedding

```
FOR p = 1 : u ; q = 1 : v
    IF P_{x,y} = S''
        IF G_i (p,q) = 1
            G_i (p,q) = 0
        ELSE
            G_i (p,q) = 1
        END
    END
END
```

3. The Proposed Method

Inspired by Wu et al.'s scheme [25], in this paper, we propose an innovative data-hiding scheme for AMBTC image compression based on the combination theory. Figure 2 shows the flowchart of the proposed data hiding scheme, consisting of image compression and data embedding. The proposed scheme involves embedding and extracting procedures. Section 3.1 provide the embedding procedures. While, Section 3.2 present the extracting procedures.

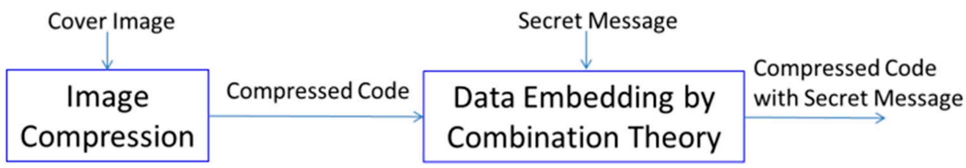

Figure 2. The flowchart of the proposed scheme**.**

3.1. The Embedding Procedures

In this part, we present the procedures of concealing confidential data into the compressed image using a hidden position matrix which generated by the combination theory. Our proposed embedding procedure is explained in depth as follows.

Input: an original image *TI*, with R width and S height, confidential data *S*.

Output: Compressed stego image *TI'*.

Given an original image *TI*, with R width and S height, segment into the n×n non-overlapping block image.

Step 1. Compress the original image block to obtain the bitmap value, *Bm,* according to Section 2.1.

Step 2. Embed the confidential data *S* into the bitmap *Bm* according to Section 2.2.

An example is given further to describe the proposed scheme for better understanding.

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Input: Suppose we have a block size of 4×4 pixels of an image. The block consisting the original pixel values {44, 61, 72, 58, 74, 65, 79, 62, 127, 93, 75, 56, 112, 117, 103, 60}. The confidential data stream S that must be concealed is (1101)2.

Step 1. Compress the original image block by using the AMBTC method. Figure 3 is the AMBTC encoding of the given pixel value.

44	61	72	58
74	65	79	62
127	93	75	56
112	117	103	60

(**a**)

0	0	0	0
0	0	1	0
1	1	0	0
1	1	1	0

(**b**)

Figure 3. AMBTC Encoding: (**a**) Original pixel value; (**b**) Bitmap.

Step 2. Embed the confidential data bits into a bitmap by implementing the combination theory as explained in Section 2.1.

0	0	0	0
0	0	1	0
1	1	0	0
1	1	1	0

(**a**)

⊗

A	B	C	D
AB	AC	AD	BC
BD	CD	ABC	ABD
BCD	ACD	ABCD	A

(**b**)

=

0	0	0	0
0	0	AD	0
BD	CD	0	0
BCD	ACD	ABCD	0

(**c**)

Figure 4. Secret position matrix generation: (**a**) Bitmap; (**b**) Secret position matrix P; (**c**) New secret position matrix P′.

0	0	0	0
0	0	AD	0
BD	CD	0	0
BCD	ACD	ABCD	0

SUM (A)=3

(**a**)

0	0	0	0
0	0	AD	0
BD	CD	0	0
BCD	ACD	ABCD	0

SUM (B)=3

(**b**)

0	0	0	0
0	0	AD	0
BD	CD	0	0
BCD	ACD	ABCD	0

SUM (C)=4

(**c**)

0	0	0	0
0	0	AD	0
BD	CD	0	0
BCD	ACD	ABCD	0

SUM (D)=6

(**d**)

Figure 5. Secret matrix calculation: (**a**) SUM of (A); (**b**) SUM of (B); (**c**) SUM of (C); (**d**) SUM of D.

$$S'_r = (1100)$$

$$Sr \neq S'_r \text{ ,} 1101 \neq 1100$$

$$S'' = (ABCD) \odot ((1101) \oplus (1100)) = (ABCD) \odot (0001) = D$$

0	0	0	0
0	0	1	0
1	1	0	0
1	1	1	0

(**a**)

0	0	0	1
0	0	1	0
1	1	0	0
1	1	1	0

(**b**)

62	62	62	62
62	62	105	105
105	105	62	62
105	105	105	62

(**c**)

62	62	62	105
62	62	105	105
105	105	62	62
105	105	105	62

(**d**)

Figure 6. Final result: (**a**) Original bitmap; (**b**) Stego bitmap; (**c**) Reconstructed original image; (**d**) Reconstructed stego image.

3.2. The Extraction Procedures

The extracting procedures are performed to retrieve confidential data. Our proposed extracting procedure is explained in depth below.

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Step 1. Calculate the new matrix $P' = P \odot G'_i$ where $p'_{x,y} = P_{x,y} \times G'_{i(x,y)}$ for all p=1, 2,…, u, and q=1, 2,…, v.

Step 2. Calculate the total amount of each confidential data bit $T(S_r), r = 1, 2, \ldots, k$ in the new matrix P' using Algorithm 3.

Algorithm 3 Confidential Data Calculation

```
FOR p = 1 : u ; q = 1 : v
    IF P'x,y hasSr
        T(Sr) = T(Sr) +1
    END
END
```

Step 3. Reassemble the confidential data bit $S_r = S_r \in 0,1, r = 1,2, \ldots, b,$ using (10).

$$S_r = T(S_r) \ mod \ 2 \tag{10}$$

4. Experimental Results

We performed extensive experiments to determine the efficacy of our proposed data-hiding technique. Assessment is conducted to determine hiding capacity and imperceptibility. We utilize the common test grayscale images, known as Airplane, Baboon, Barbara, Boat, Lena, and Peppers, as shown in Figure 7a,d,g,j,m,p, respectively. The entirety test images are 512×512 pixels in size. We performed a binary confidential data which produced by a pseudo-random number generator.

The hiding capacity is identifies by the number of bits. While identifies by image quality. To assess image quality, the common used parameter is the peak signal-to-noise ratio (PSNR) as defined in Equation (11).

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{11}$$

The mean square error (MSE) is defined in Equation (12).

$$MSE = \frac{1}{N \times N}\sum_{i=1}^{N}\sum_{j=1}^{N}(TI_{ij} - TI'_{ij})^2 \tag{12}$$

Where TI_{ij} is the pixel in position of the *i*-th row and the *j*-th column of image TI, and TI'_{ij} is the pixel in the *i*-th row and the *j*-th column image TI'

The experimental findings are presented in Table 1, where PSNRs, MSEs, and hiding capacity are shown. According to the experimental findings, the image Lena and Pepper achieved the highest hiding capacity. Lena's embedding capacity is 201364. Moreover, Pepper's embedding capacity is 197632. On the other hand, in terms of image quality, the image Airplane and Baboon achieved the best image quality with less visual distortion. The airplane's PSNR value is 38.25 dB, and Baboon's PSNR value is 37.97 dB, respectively.

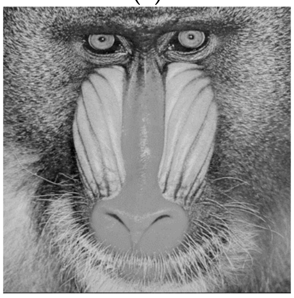
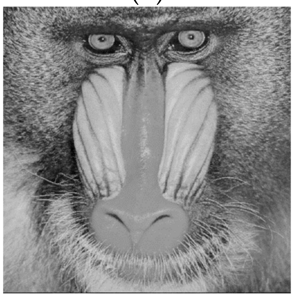
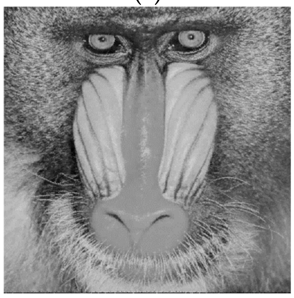
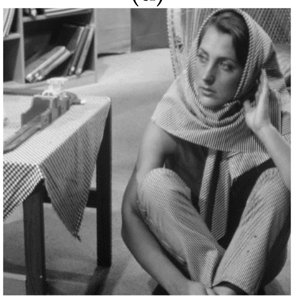
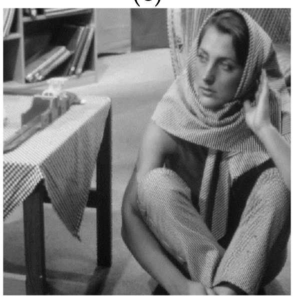
Further testing was performed by comparing our proposed method to the related method developed by Lee et al.'s scheme [17]. The performance comparison of our proposed scheme and Lee et al.'s scheme can be seen in Table 1. The scheme varied in different thresholds, i.e., TH=0, TH=5, TH=10, TH=20, TH=30, TH=40, and TH=50. It can be seen in Figure 13. Among the 6 test images, our scheme is superior in terms of image quality.

In summary, the main advantage of our proposed scheme:

1. The capacity of our scheme is between thresholds (TH 5 & TH10) of Lee et al.'s scheme [17].
2. If the picture is complex (non-smooth), the capacity of our proposed method is more excellent than Lee *et al.*'s scheme [17].
3. The qualification of images (PSNR) is higher than Lee *et al.*'s scheme [17]. Moreover, our proposed method performs satisfying image quality in complex images.


(a)

(b)

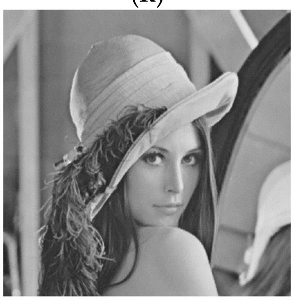
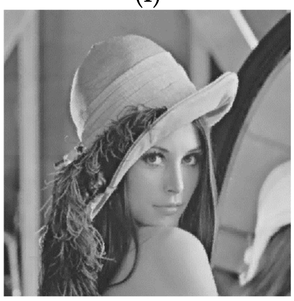
(c)

(d)

(e)

(f)

(g)

(h)

(i)

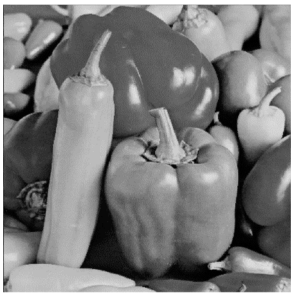
(j)

(k)

(l)

(m)

(n)

(o)


(p)


(q)

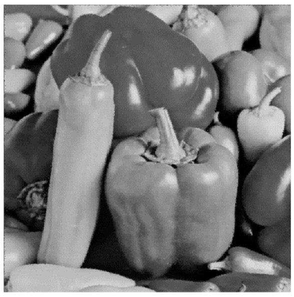

(r)

Figure 7. This is a figure. Image Experimental Results : (**a**) Airplane Original Image; (**b**) Airplane AMBTC; (**c**) Airplane Stego Image; (**d**) Baboon Original Image; (**e**) Baboon AMBTC; (**f**) Baboon Stego Image; (**g**) Barbara Original Image; (**h**) Barbara AMBTC; (**i**) Barbara Stego Image; (**j**) Boat Original Image; (**k**) Boat AMBTC; (**l**) Boat Stego Image; (**m**) Lena Original Image; (**n**) Lena AMBTC; (**o**) Lena Stego Image; (**p**) Pepper Original Image; (**q**) Pepper AMBTC; (**r**) Pepper Stego Image.

Table 1. Performance Comparison.

Image	**Metrics**	**Lee et al Scheme** [17]							**Proposed**
		TH 50	**TH 40**	**TH 30**	**TH 20**	**TH 10**	**TH 5**	**TH 0**	
Airplane	PSNR	33.89	33.86	33.86	33.90	33.87	33.83	33.86	**38.25**
	MSE	26.53	26.72	26.70	26.49	26.64	26.93	26.72	**9.72**
	Capacity	319808	311984	301424	285968	250432	188800	81920	195928
Baboon	PSNR	30.87	30.82	30.82	30.84	30.85	30.83	30.85	**37.97**
	MSE	53.17	53.80	53.86	53.60	53.41	53.76	53.41	**10.36**
	Capacity	281136	249920	216304	179504	128112	97424	81920	104284
Barbara	PSNR	31.94	31.93	31.95	31.94	31.93	31.99	31.97	**37.59**
	MSE	41.61	41.70	41.48	41.62	41.66	41.14	41.27	**11.31**
	Capacity	302544	285584	263808	232496	190128	131440	81920	151840
Boat	PSNR	31.73	31.71	31.70	31.70	31.77	31.72	31.74	**36.27**
	MSE	43.63	43.84	43.90	43.90	43.21	43.67	43.52	**15.34**
	Capacity	321520	311568	297024	269280	191600	113200	81920	158440
Lena	PSNR	33.43	33.43	33.40	33.422	55.47	33.38	33.42	**37.42**
	MSE	29.51	29.50	29.66	29.56	18.43	29.80	29.58	**11.76**
	Capacity	335680	329152	318032	298880	254976	175248	81920	201364
Pepper	PSNR	32.68	32.73	32.68	32.65	32.70	32.68	32.69	**35.89**
	MSE	35.00	34.66	35.019	35.29	34.86	35.01	34.96	**16.72**
	Capacity	329536	324208	315904	300720	242848	135440	81920	197632
Average	PSNR	32.38	32.36	32.36	32.38	32.37	32.39	32.38	**37.24**
	MSE	38.60	38.71	38.69	38.55	38.63	38.50	38.59	**12.54**
	Capacity	314664	301671	285226	260980	209447	140108	86993	168248

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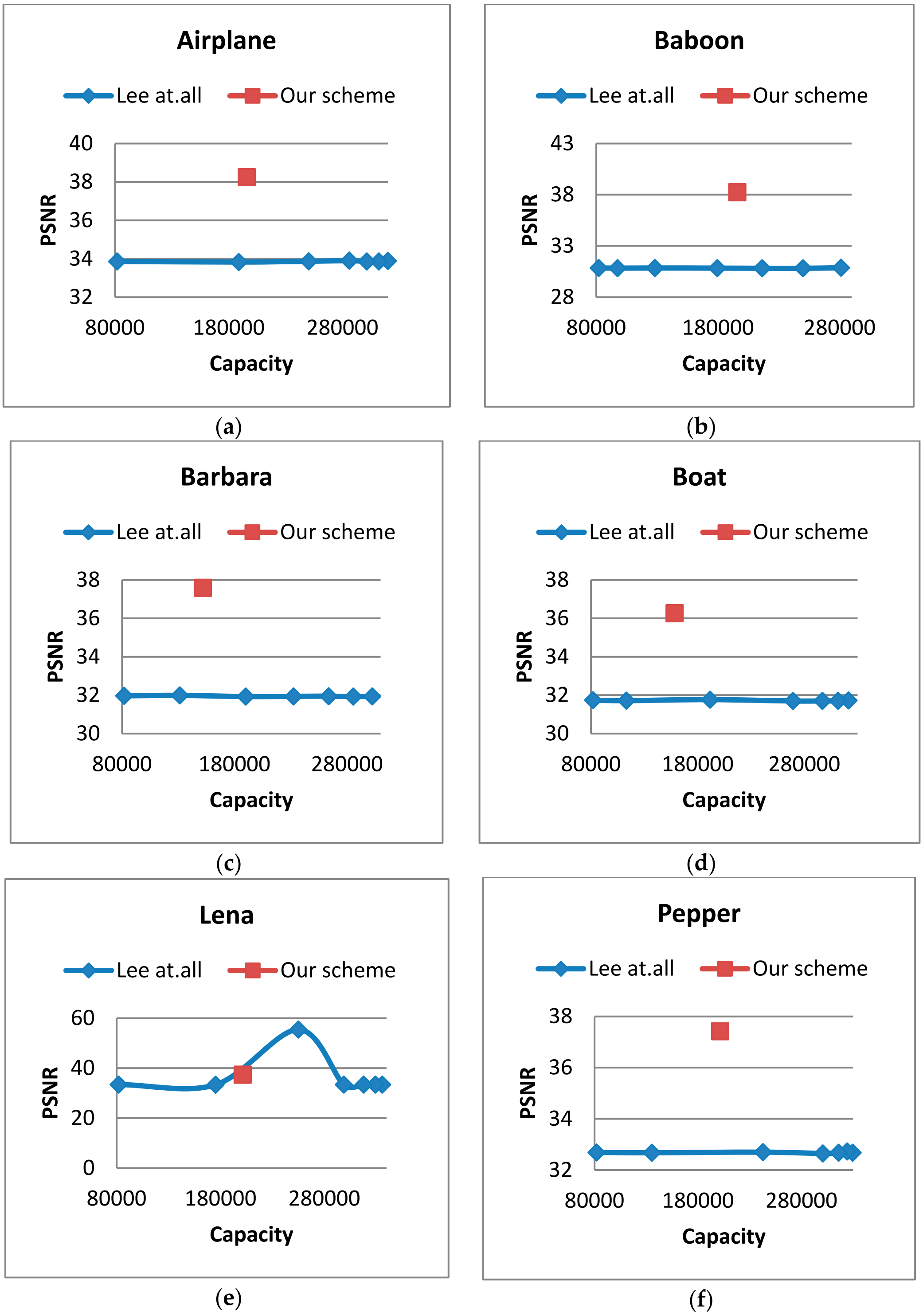

Figure 8. This is a figure. The graphic of performance comparison: (**a**) Airplane; (**b**) Baboon; (**c**) Barbara; (**d**) Boat; (**e**) Lena; (**f**) Pepper.

5. Conclusions

This paper proposed a highly imperceptible data-hiding method in AMBTC compressed images with the combination theory. Using the combination theory in the image-compressed domain, we can achieve higher embedding capacity without considering the threshold value for determining the smooth or complex image block. Further, our proposed scheme performs well with a practical and low-computation algorithm. The experimental results show that the proposed scheme achieved satisfied modified compressed image quality and high hiding capacity. Moreover, the proposed scheme performs better than Lee et al.'s scheme [17] in complex images.

For further development, our proposed scheme can be very effective and adopted appropriately in the medical image for securing electronic patient information because our proposed scheme induces invisible modification of image quality.

Author Contributions: The author's contribution to this manuscript is stated as follows: Conceptualization: Kurnia Anggriani; methodology: Kurnia Anggriani; software: Shu-Fen Chiou; validation: Nan-I Wu; formal analysis: Nan-I Wu; investigation: Shu-Fen Chiou; data curation: Shu-Fen Chiou; writing—original draft preparation: Kurnia Anggriani; writing—review and editing: Min-Shiang Hwang; project administration: Min-Shiang Hwang; funding acquisition: Min-Shiang Hwang. All authors have read and agreed to the published version of the manuscript.

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