

# Reversible Data Hiding-Based Approach for Intra-Frame Error Concealment in H.264/AVC

Kuo-Liang Chung, *Senior Member, IEEE*, Yong-Huai Huang, Po-Chun Chang, and Hong-Yuan Mark Liao, *Senior Member, IEEE*

**Abstract**—Error concealment plays an important role in robust video transmission. Recently, Chen and Leung presented an efficient data hiding-based (DH-based) approach to recover corrupted macroblocks from the intra-frame of an H.264/AVC sequence, but it suffers from the quality degradation problem. Since the quantized discrete cosine transform coefficients of an H.264/AVC sequence tend to form a Laplace distribution, we therefore propose a reversible DH-based approach for intra-frame error concealment based on this characteristic. Our design is able to achieve no quality degradation. Experimental results demonstrate that the quality of recovered video sequences obtained by our approach is indeed superior to that of the DH-based method. In addition, the quality advantage of our approach is illustrated when compared with the previous five related methods.

**Index Terms**—Error concealment, H.264/AVC, intra-frame, motion vector, quantized discrete cosine transform, reversible data hiding.

## I. INTRODUCTION

H.264/AVC video compression standard [1], under the same bitrate, has better peak signal-to-noise ratio (PSNR) and visual quality performance when compared with MPEG-2, MPEG-4, and H.263. It is now the most frequently used technique for compressing video sequences. Since the transmission process in a network environment is error prone, the quality of service cannot be guaranteed. Therefore, error concealment is considered a good protection for better transmission quality.

In the past decade, many error concealment algorithms have been developed to recover the corrupted macroblocks (MBs)

Manuscript received August 17, 2009; revised January 22, 2010; accepted March 17, 2010. Date of publication September 20, 2010; date of current version November 5, 2010. The work of K.-L. Chung was supported by the National Science Council of China, Taipei, Taiwan, under Contract NSC98-2221-E-011-084-MY3. The work of Y.-H. Huang was supported by the National Science Council of China, under Contract NSC97-2811-E-011-015. The work of H.-Y. M. Liao was completed when visiting the Department of Computer Science and Information Engineering, National Taiwan University of Science and Technology, Taiwan, from March 2009 to August 2009. This paper was recommended by Associate Editor X. Li.

K.-L. Chung and P.-C. Chang are with the Department of Computer Science and Information Engineering, National Taiwan University of Science and Technology, Taipei 10672, Taiwan (e-mail: k.l.chung@mail.ntust.edu.tw; iboss39@gmail.com).

Y.-H. Huang is with the Institute of Computer and Communication Engineering and the Department of Electronic Engineering, Jinwen University of Science and Technology, Hsin-Tien, Taipei 23154, Taiwan (e-mail: yonghuai@ms28.hinet.net).

H.-Y. M. Liao is with the Institute of Information Science, Academia Sinica, Taipei 115, Taiwan (e-mail: yonghuai@ms28.hinet.net).

Digital Object Identifier 10.1109/TCSVT.2010.2077577

in inter-frames (P-frames) [2]–[6], intra-frames (I-frames) [7]–[14], and hybrid of inter and intra-frames [15]–[21] of coded video sequences. The error concealment done within intra-frames is more important than that done within inter-frames since an I-frame is the first frame in a group of pictures (GOPs) and the error occurred in an I-frame will be propagated to subsequent P-frames.

In [14], Chen and Leung proposed an efficient encoder-side data hiding (DH-based) approach for intra-frame error concealment in H.264/AVC. This error concealment method has less computational overhead at the decoder side and is very suitable for environments that have limited computation resources, such as mobile devices. In their method, the motion estimation process is first performed on two consecutive I-frames and the motion vector (MV) of each MB is embedded into quantized discrete cosine transform (QDCT) coefficients of its neighboring MB. At the decoder side, the MV information of each corrupted MB can be extracted from the neighboring MB and the corrupted MB can be recovered by performing the motion compensation process. Experimental results show that the DH-based method has better image quality when compared to the error concealment method proposed in JM 12.0 [22] and other I-frame-based error concealment methods [17], [20], [21]. However, a DH-based error concealment (DHEC) method suffers from the quality degradation problem after embedding MVs into QDCT coefficients. The motivation of this letter is to present a reversible DHEC method to solve the quality degradation problem.

By observing the distribution of QDCT coefficients in each MB of an H.264/AVC sequence, we find that it forms a Laplace distribution. In addition, a large number of zero QDCT coefficients exist in this distribution. This observation inspires us to design a reversible data hiding (RDH) scheme to embed the MV of that block into the QDCT coefficients of the neighboring MB. For each MB, after increasing positive QDCT coefficients by one, if the scanned bit of MV is zero, the corresponding zero QDCT coefficient remains its value. Otherwise, the corresponding zero QDCT coefficient is changed to one. The embedded MVs can be extracted easily by checking the values of embedded QDCT coefficients. Experimental results indicated that our proposed RDH-based error concealment method has better quality than previous DHEC method. The quality advantage of our approach is also demonstrated when compared with the orientation adaptive interpolation (OAI) approach by Li and Orchard [8], and the

four related methods by Belfiore et al. [17], Friebe and Kaup [20], Ng et al. [21], and the one in JM 12.0.

## II. CHEN AND LEUNG'S DH-BASED ERROR CONCEALMENT METHOD

In this section, we briefly survey the DHEC method proposed by Chen and Leung [14]. Let  $I_k$ ,  $k > 0$ , denote the current intra-frame and  $I_{k-1}$  denote the previous intra-frame in an H.264/AVC sequence. Suppose an intra-frame  $I_k$  is partitioned into a set of  $16 \times 16$  MBs,  $MB_{i,j}$ , where  $i \in \{0, 1, 2, \dots, \frac{h}{16}\}$  and  $j \in \{0, 1, 2, \dots, \frac{w}{16}\}$ .  $h$  and  $w$  here denote the height and the width of  $I_k$ , respectively. For easy exposition, we assume  $h$  and  $w$  are multiples of 16. After performing motion estimation with search range  $\pm 15$  and half-pixel accuracy on  $I_{k-1}$  and  $I_k$ , the MV of each  $MB_{i,j}$ , called  $MV_{i,j}$ , is obtained. It is easy to verify that 12 bits ( $= 2 \times (\lceil \log_2(2 \times 15 + 1) \rceil + 1)$ ) are required to store  $MV_{i,j}$ .

In Chen and Leung's method, a circular embedding scheme is used to embed the MV of each MB to its neighboring MB. Based on this embedding strategy, four  $2 \times 2$  neighboring MBs,  $MB(p, q)$ ,  $MB(p, q+1)$ ,  $MB(p+1, q)$ , and  $MB(p+1, q+1)$ , where  $p = \{0, 2, 4, \dots, \frac{h}{16}\}$  and  $q = \{0, 2, 4, \dots, \frac{w}{16}\}$ , are grouped into an MB set. For each MB set, we embed  $MV(p, q)$  into  $MB(p, q+1)$ , and embed  $MV(p, q+1)$ ,  $MV(p+1, q)$ , and  $MV(p+1, q+1)$  into  $MB(p+1, q)$ ,  $MB(p+1, q+1)$ , and  $MB(p, q)$ , respectively. At the decoder side, if an MB, say  $MB(p, q)$ , is corrupted, its original  $MV(p, q)$  can be extracted from its neighboring MB,  $MB(p, q+1)$ . For easy exposition, the term  $MB_C$  is used to denote the current processed MB and its MV, say  $MV_C$ , will be embedded into the neighboring MB, say  $MB_N$ , determined by the above circular embedding scheme. In what follows, we will explain how to embed  $MV_C$  into  $MB_N$  by perturbing the QDCT coefficients of  $MB_N$ .

According to zig-zag scan order, the 16 2-D QDCT coefficients of a  $4 \times 4$  block in  $MB_N$ , say  $F_N(0)$ ,  $F_N(1)$ , ..., and  $F_N(15)$ , are transformed into a 1-D sequence from low-frequency coefficients to high-frequency coefficients. To reduce quality degradation caused by embedding  $MV_C$  into QDCT coefficients of  $MB_N$ , the first three QDCT coefficients,  $F_N(0)$ ,  $F_N(1)$ , and  $F_N(2)$ , are not considered in the embedding process. Let  $b_C(0)$ ,  $b_C(1)$ , ..., and  $b_C(11)$  denote the 12 bits of  $MV_C$ . The process of embedding these 12 bits into  $F_N(i)$ 's for  $3 \leq i \leq 14$  is performed by

$$\bar{F}_N(i) = \begin{cases} F_N(i) + 1 & \text{if } b_C(i-3) = 1 \text{ and } F_N(i) \text{ is even} \\ F_N(i) & \text{if } b_C(i-3) = 1 \text{ and } F_N(i) \text{ is odd} \\ F_N(i) & \text{if } b_C(i-3) = 0 \text{ and } F_N(i) \text{ is odd} \\ F_N(i) - 1 & \text{if } b_C(i-3) = 0 \text{ and } F_N(i) \text{ is even.} \end{cases} \quad (1)$$

At the decoder side, if  $MB_C$  is corrupted, we can extract each bit of  $MV_C$  from  $MB_N$  by

$$b_C(i-3) = \begin{cases} 1, & \text{if } \text{mod}(\bar{F}_N(i), 2) = 1 \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

from the extracted  $MV_C$ ,  $MB_C$  can be recovered by performing the motion compensation process to find the best matched MB

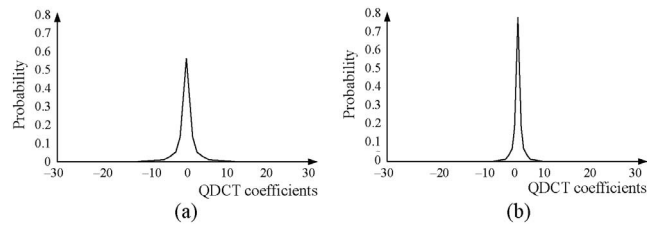


Fig. 1. Histograms of QDCT coefficients for two H.264 sequences. (a) *Mobile*. (b) *Coastguard*.

from the previous intra-frame  $I_{k-1}$ . From (1), it is known that the QDCT coefficients have been perturbed, so the quality of the decompressed image will be degraded.

## III. PROPOSED RDH-BASED METHOD FOR INTRA-FRAME ERROR CONCEALMENT

In this section, the proposed QDCT-based RDH scheme is presented for intra-frame error concealment. First, we compute the distribution of the 256 QDCT coefficients of  $16 \times 4 \times 4$  blocks in one MB, which was computed by running JM 12.0 on *Mobile* and *Coastguard* video sequences. Fig. 1 illustrates the two histograms of QDCT coefficients of *Mobile* and *Coastguard* video sequences. From the two distributions, it is not difficult to find out that they are very similar to Laplace distributions (with zero mean) and the statistics indicated that the number of zero QDCT coefficients in one MB was at least 153 ( $= 0.6 \times 256$ ). This amount can guarantee enough DH capacity for hiding the MVs into the zero QDCT coefficients by using the histogram modification technique developed by [23].

We now present the proposed QDCT-based RDH scheme. Instead of using the circular embedding scheme [14], a modified circular embedding scheme is presented to embed each MV into the corresponding MB. From the modified circular embedding scheme, for each MB set with four MBs, we embed  $MV(p, q)$ ,  $MV(p, q+1)$ ,  $MV(p+1, q)$ , and  $MV(p+1, q+1)$  into  $MB(p, q+1)$ ,  $MB(p+1, q+1)$ ,  $MB(p, q)$ , and  $MB(p+1, q)$ , respectively. Fig. 2 shows all six cases for two corrupted MBs in an MB set where shadowed MBs denote corrupted MBs. The cases in Fig. 2(a) and (b) are viewed as the first straight-line pattern and the second straight-line pattern, respectively. The two cases in Fig. 2(c) are viewed as the checker board pattern. The proposed modified circular embedding scheme can recover two corrupted MBs for the checker board pattern and is better than Chen and Leung's embedding scheme which can recover only one corrupted MB for the same pattern. Vice versa, Chen and Leung's embedding scheme can recover two corrupted MBs for the second straight-line pattern in Fig. 2 while the proposed scheme can recover only one corrupted MB. The recovery capability of both schemes is the same for the first straight-line pattern in Fig. 2. Since H.264 provides the flexible MB ordering (FMO) mode to encode the video sequence, all MBs in each frame could be classified into two groups based on the checker board pattern, so that each group is encoded separately. As a result, all corrupted MBs can be recovered completely when losing a complete slice in the intra-

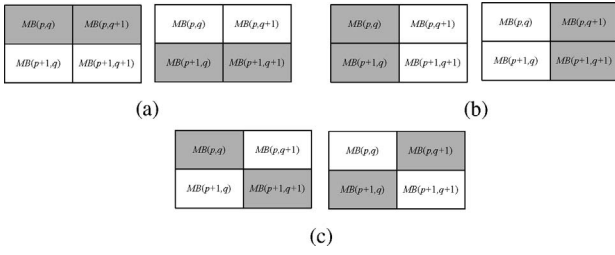


Fig. 2. All six cases for two corrupted MBs (see shadowed MBs) in an MB set. (a) First straight-line pattern. (b) Second straight-line pattern. (c) Checkerboard pattern.

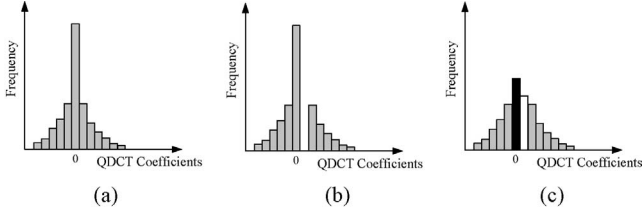


Fig. 3. Embedding MV into QDCT coefficients. (a) Minimal set  $F_N^m$ . (b) Shift positive QDCT coefficients to the right position. (c) After embedding MV into zero QDCT coefficients.

frame. On the other hand, our proposed embedding scheme has better recovering advantage when the corrupted MBs are in FMO mode which is more common than the random error pattern.

According to the proposed modified circular embedding scheme, the zero QDCT coefficients of  $MB_N$  are used to hide  $MV_C$  of  $MB_C$ . Since  $MV_C$  has 12 bits only, there is no need to involve all QDCT coefficients of  $MB_N$  in the hiding process. To reduce computation load, we construct a minimal set of QDCT coefficients based on zig-zag scanning order such that in the identified minimal set,  $F_N^m$ , there are exactly 12 zero QDCT coefficients. Let these zero QDCT coefficients be denoted as  $F_N^{m,Z} = \{F_N^{m,Z}(0), F_N^{m,Z}(1), \dots, F_N^{m,Z}(11)\}$ . The nonzero QDCT coefficients in the minimal set,  $F_N^m$ , can be denoted as  $F_N^{m,NZ} = \{F_N^{m,NZ}(0), F_N^{m,NZ}(1), \dots, F_N^{m,NZ}(|F_N^m| - 13)\}$ .

Now we can modify the histogram of the minimal set  $F_N^m$ . For better illustration, we use Fig. 3(a) to show how  $F_N^m$  looks like. As shown in Fig. 3(b), (3) is used to shift all bins with positive QDCT coefficients to the right position

$$\bar{F}_N^{m,NZ}(i) = \begin{cases} F_N^{m,NZ}(i) + 1 & \text{if } F_N^{m,NZ}(i) > 0 \\ F_N^{m,NZ}(i) & \text{otherwise} \end{cases} \quad (3)$$

for  $0 \leq i \leq |F_N^m| - 13$ . From the shifted histogram, the process for hiding the 12 bits of  $MV_C$  into the 12 zero QDCT coefficients in  $F_N^{m,Z}$  can be done by

$$\bar{F}_N^{m,Z}(n) = \begin{cases} F_N^{m,Z}(n) & \text{if } b_C(n) = 0 \\ 1 & \text{otherwise} \end{cases} \quad (4)$$

for  $0 \leq n \leq 11$ .

Up to now, the 12 bits of  $MV_C$  have been stored in  $F_N^{m,Z}$ ; some zero QDCT coefficients in  $F_N^{m,Z}$  have been set to 1s and the remaining zero QDT coefficients in  $F_N^{m,Z}$  are not changed. To extract  $MV_C$  from  $MB_N$  at the decoder side, we construct a minimal set  $\bar{F}_N^m$  of QDCTs based on zig-zag scanning order such that in  $\bar{F}_N^m$ , there are exactly 12 QDCT

TABLE I  
AVERAGE PSNR DEGRADATION AND BITRATE INCREMENT RATE BY THE DHEC METHOD AND OUR PROPOSED RDHEC METHOD

QP	8	18	28	38	48	
PSNR degradation	DHEC	0.12	0.18	0.42	0.93	1.59
	RDHEC	0.00	0.00	0.00	0.00	0.00
Bitrate increment rate (%)	DHEC	0.20	0.67	2.30	9.89	61.23
	RDHEC	0.38	0.67	2.03	8.20	42.30

coefficients with values 0 or 1. Let the 12 QDCT coefficients with values 0 or 1 in  $\bar{F}_N^m$  be denoted by  $\bar{F}_N^{m,Z} = \{\bar{F}_N^{m,Z}(0), \bar{F}_N^{m,Z}(1), \dots, \bar{F}_N^{m,Z}(11)\}$ . The other QDCT coefficients in the minimal set  $\bar{F}_N^m$  are denoted by  $\bar{F}_N^{m,NZ} = \{\bar{F}_N^{m,NZ}(0), \bar{F}_N^{m,NZ}(1), \dots, \bar{F}_N^{m,NZ}(|\bar{F}_N^m| - 13)\}$ . Thus, each bit  $b_C(n)$  of  $MV_C$  can be extracted by

$$b_C(n) = \begin{cases} 0 & \text{if } \bar{F}_N^{m,Z}(n) = 0 \\ 1 & \text{otherwise} \end{cases} \quad (5)$$

for  $0 \leq n \leq 11$ . Further, we can recover the original  $F_N^{m,Z}(n)$  and  $F_N^{m,NZ}(i)$ ,  $0 \leq n \leq 11$  and  $0 \leq i \leq |F_N^m| - 13$ , by performing

$$F_N^{m,Z}(n) = 0 \quad (6)$$

$$F_N^{m,NZ}(i) = \begin{cases} \bar{F}_N^{m,NZ}(i) - 1 & \text{if } \bar{F}_N^{m,NZ}(i) > 0 \\ \bar{F}_N^{m,NZ}(i) & \text{otherwise} \end{cases} \quad (7)$$

since the perturbed QDCT coefficients in  $MB(p,q+1)$  can be recovered completely by (6) and (7), our proposed QDCT-based intra-frame error concealment method for H.264/AVC sequences has no quality degradation when compared to the previous DH-based method.

#### IV. EXPERIMENTAL RESULTS

In this section, we compare the performance among the method used in JM 12.0, the OAI method proposed by Li and Orchard [8], the perceptually optimized mode selection (POMS) method proposed by Belfiore et al. [17], the spatiotemporal fading (STF) method proposed by Friebe and Kaup [20], the edge weighted spatiotemporal search (EWSTS) method proposed by Ng et al. [21], the DHEC method proposed by Chen and Leung [14], and our proposed RDH-based error concealment (RDHEC) method for intra-frame error concealment in H.264/AVC sequences. The seven concerned methods were implemented on the IBM compatible computer with Intel Core 2 Quad Q8400 CPU 2.67 GHz and 2 GB RAM. The operating system used is Microsoft Windows 7 and the program developing environment is Visual C++ 2005. The implementation platform was JM 12.0. The source codes of the DHEC and the RDHEC have been uploaded in [24].

Six test QCIF sequences, *Foreman*, *Mobile*, *Silent*, *Coastguard*, *Carphone*, and *Container*, were adopted to evaluate the performance comparison for the seven methods. The GOP structure is set to IPPPP and five different quantization parameters (QPs), 8, 18, 28, 38, and 48, are considered for encoding the six sequences.

TABLE II  
PSNRS OF RECOVERED SEQUENCES FOR 20% LOSS OF INTRA-FRAME MBS

	<i>Foreman</i>	<i>Mobile</i>	<i>Silent</i>	<i>Coastguard</i>	<i>Carphone</i>	<i>Container</i>	Average
JM 12.0	26.40	21.61	27.14	25.76	25.63	26.67	25.53
POMS	28.18	25.06	29.48	27.63	28.50	29.68	28.09
EWSTS	28.87	25.69	30.01	28.09	29.49	32.44	29.10
STF	29.35	24.95	31.10	28.38	30.33	31.66	29.30
OAI	28.62	23.36	28.25	27.59	27.90	27.59	27.22
DHEC	29.64	26.77	30.91	29.13	30.85	33.09	30.06
RDHEC	29.86	26.65	31.11	29.20	31.06	33.44	30.22

TABLE III  
PSNRS OF RECOVERED SEQUENCES FOR 50% (A COMPLETE SLICE) LOSS OF INTRA-FRAME MBS

	<i>Foreman</i>	<i>Mobile</i>	<i>Silent</i>	<i>Coastguard</i>	<i>Carphone</i>	<i>Container</i>	Average
JM 12.0	23.71	19.24	24.39	23.80	23.59	23.63	23.06
POMS	24.61	21.36	25.72	25.04	25.11	25.42	24.54
EWSTS	24.13	20.93	26.64	24.65	26.74	24.41	24.59
STF	25.06	20.98	26.04	25.43	26.09	25.36	24.83
OAI	24.10	19.39	24.29	24.26	24.26	23.60	23.32
DHEC	25.10	22.53	28.20	26.05	27.80	31.13	26.80
RDHEC	26.09	23.16	29.47	26.81	28.86	32.78	27.86

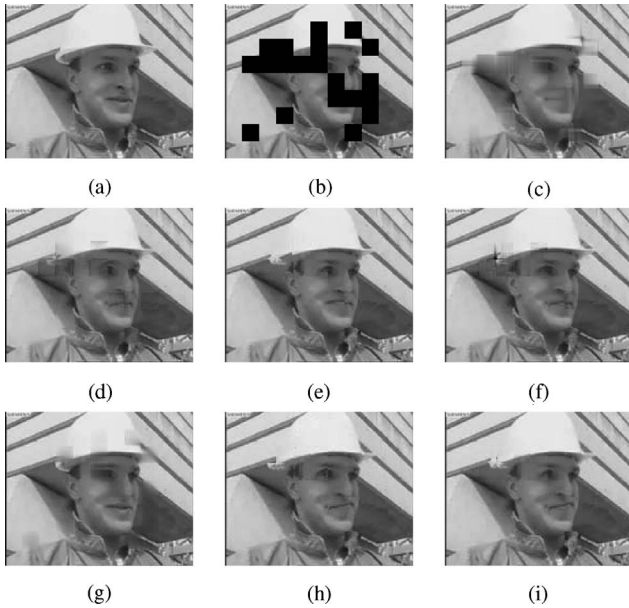


Fig. 4. Concealed results for *Foreman* sequence with 20% loss of intra-frame MBS. (a) Original frame. (b) Missing blocks. (c)–(i) are recovered frames by JM12.0, POMS method, EWSTS method, STF method, OAI method, DHEC method, and RDHEC, respectively.

After running the concerned DHEC method and RDHEC method on the six test sequences, Table I shows the average PSNR degradation and bitrate increment rate in H.264 sequences. Table I indicates that expect the case  $QP \geq 8$ , our proposed method need less bitrate overhead when compared to the DHEC method. It is also observed that the proposed RDHBA method has no PSNR degradation. We further compare the execution-time performance to justify the applicability of both methods. Experimental results demonstrate that the encoding execution-time overhead ratio of the proposed RDHEC (DHEC) method over the one in JM 12.0 is

16% (18%). However, the proposed RDHEC method has 5% decoding execution-time overhead ratio while the previous DHEC method has no decoding execution-time overhead. From the above experimental data, we can find that the proposed RDHEC method only has a little encoding and decoding execution-time overhead ratio and it confirms the H.264/AVC applicability of the proposed method.

For comparing the error concealment performance in the concerned methods, we first take six sequences with 20% random loss of intra-frame MBS as the test sequences. The average PSNRs of recovered sequences obtained by the concerned seven methods are shown in Table II and it is observed that our proposed RDHEC method has the best PSNR performance in the seven concerned methods. Next, we consider the error model that a complete slice is lost. For this error model, the FMO mode is adopted and for each intra-frame, 50% MBS are corrupted. The average PSNRs of recovered sequences obtained by the concerned seven methods are illustrated in Table III and it is clear that our proposed RDHEC method still has the best PSNR performance in the seven concerned methods.

For exposing the visual effect of the seven methods, Fig. 4(c)–(i) and Fig. 5(c)–(i) illustrate the concealed results for *Foreman* sequence with 20% and 50% (a complete slice) loss of intra-frame MBS, respectively. It is observed that the previous DHEC method and our proposed RDHEC method have similar visual effect and both methods have better visual effect when compared with the other five methods.

## V. CONCLUSION

Based on the RDH-based scheme, the proposed error concealment method for I-frames in H.264/AVC sequences has been presented. By using the histogram modification technique, the proposed RDHEC method embeds MVs of MBS into zero QDCT coefficients and the corrupted MBS can be recovered completely. Different from the previous

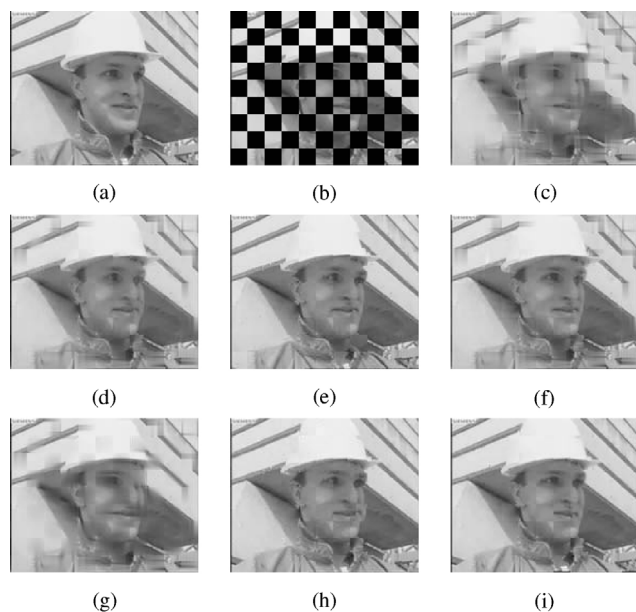


Fig. 5. Concealed results for *Foreman* sequence with 50% (a complete slice) loss of intra-frame MBs. (a) Original Frame. (b) Missing blocks. (c)–(i) are recovered frames by JM12.0, POMS method, EWSTS method, STF method, OAI method, DHEC method, and RDHEC, respectively.

DHEC method by Chen and Leung, the proposed method has no image quality degradation since the perturbed QDCT coefficients can be recovered to the original ones completely. Experimental results demonstrate that the quality performance of our RDH-based error concealment method is superior to the DH-based concealment method. It is an interesting issue to apply the proposed RDH-based method to the inter-frame error concealment since the MV of each P-frame can also be embedded into QDCT coefficients of its neighboring MB.

#### REFERENCES

- [1] I. E. G. Richardson, *H.264 and MPEG-4 Video Compression*. New York: Wiley, 2003.
- [2] M. J. Chen, C. S. Chen, and M. C. Chi, "Temporal error concealment algorithm by recursive block-matching principle," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 15, no. 11, pp. 1385–1393, Nov. 2005.
- [3] K. L. Chung, T. H. Huang, and P. H. Liao, "Efficient hybrid error concealment algorithm based on adaptive estimation scheme," *J. Visual Commun. Image Representation*, vol. 18, no. 4, pp. 331–340, Aug. 2007.
- [4] W. N. Lie and T. C. I. Lin, "Prescription-based error concealment technique for video transmission on error-prone channels," *J. Visual Commun. Image Representation*, vol. 18, no. 4, pp. 310–321, Aug. 2007.
- [5] Y. Chen, Y. Hu, O. C. Au, H. Li, and C. W. Chen, "Video error concealment using spatio-temporal boundary matching and partial differential equation," *IEEE Trans. Multimedia*, vol. 10, no. 1, pp. 2–15, Jan. 2008.
- [6] J. Wu, X. Liu, and K. Y. Yoo, "A temporal error concealment method for H.264/AVC using motion vector recovery," *IEEE Trans. Consumer Electron.*, vol. 54, no. 4, pp. 1880–1885, Nov. 2008.
- [7] P. Yin, B. Liu, and H. H. Yu, "Error concealment using data hiding," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Process.*, vol. 3. 2001, pp. 1453–1456.
- [8] X. Li and M. T. Orchard, "Novel sequential error-concealment techniques using orientation adaptive interpolation," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 12, no. 10, pp. 857–864, Oct. 2002.
- [9] M. Chen, M. Wu, and Y. Zheng, "Classification-based spatial error concealment for images," in *Proc. IEEE Int. Conf. Image Process.*, vol. 2. Sep. 2003, pp. 675–678.
- [10] W. Kutlmiltis and E. Hirtutiu, "An intra-frame error concealment non-linear pattern alignment and directional interpolation," in *Proc. Int. Conf. Image Process.*, vol. 2. 2004, pp. 825–828.
- [11] Y. Zhao, D. Tian, M. M. Hannukasela, and M. Gabbouj, "Spatial error concealment based on directional decision and intra prediction," in *Proc. IEEE Conf. Circuits Syst.*, vol. 3. 2005, pp. 2899–2902.
- [12] M. Chen, Y. Zheng, and M. Wu, "Classification-based spatial error concealment for visual communications," *EURASIP J. Appl. Signal Process.*, vol. 2006, no. 13438, pp. 1–17, 2006.
- [13] M. Ma, O. C. Au, L. Guo, Z. Liang, and S. H. G. Chan, "Error concealment for intra-frame losses over packet loss channels," in *Proc. Pacific Rim Conf. Multimedia*, 2007, pp. 530–538.
- [14] S. Chen and H. Leung, "A temporal approach for improving intra-frame concealment performance in H.264/AVC," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 19, no. 3, pp. 422–426, Mar. 2009.
- [15] J. Zhang, J. F. Arnold, and M. R. Frater, "A cell-loss concealment technique for MPEG-2 coded video," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 10, no. 4, pp. 659–665, Jun. 2000.
- [16] D. S. Turaga and T. Chen, "Model-based error concealment for wireless video," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 12, no. 6, pp. 483–495, Jun. 2002.
- [17] S. Belfiore, M. Grangetto, E. Magli, and G. Olmo, "Spatio-temporal video error concealment with perceptually optimized mode selection," in *Proc. Int. Conf. Acoust., Speech, Signal Process.*, vol. 5. 2003, pp. 748–751.
- [18] Y. Chen, X. Sun, F. Wu, Z. Liu, and S. Li, "Spatio-temporal video error concealment using priority-ranked region-matching," in *Proc. Int. Conf. Image Process.*, vol. 2. 2005, pp. 1050–1053.
- [19] W. L. Chen and J. J. Leou, "A new hybrid error concealment scheme for H.264 video transmission," in *Proc. Int. Conf. Wireless Commun. Mobile Comput.*, vol. 1. 2006, pp. 61–66.
- [20] M. Friebe and A. Kaup, "Fading techniques for error concealment in block-based video decoding systems," *IEEE Trans. Broadcast.*, vol. 53, no. 1, pp. 286–296, Feb. 2007.
- [21] E. S. Ng, J. Y. Tham, and S. Rahardja, "Edge weighted spatio-temporal search for error concealment," in *Proc. Int. Conf. Image Process.*, vol. 4. 2007, pp. 249–252.
- [22] *H.264AVC Reference Software JM 12.0* [Online]. Available: <http://iphome.hhi.de/suehring/tml>
- [23] Z. Ni, Y. Q. Shi, N. Ansari, and W. Su, "Reversible data hiding," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 16, no. 3, pp. 354–362, Mar. 2006.
- [24] DHEC and RDHEC [Online]. Available: <http://140.118.175.164/Huang/IEC.zip>