Whole Frame Error Concealment with an Adaptive PU-based Motion Vector Extrapolation for HEVC

Seounghwi Kim, Dongkyu Lee, and Seoung-Jun Oh

Department of Electronic Engineering, Kwangwoon University / Seoul, Korea {k2090535, dongkyu, sjoh}@media.kw.ac.kr

* Corresponding Author: Seounghwi Kim

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** Regular Paper*

***Abstract*:** Most video services are transmitted in wireless networks. In a network environment, a packet of video is likely to be lost during transmission. For this reason, numerous error concealment (EC) algorithms have been proposed to combat channel errors. On the other hand, most existing algorithms cannot conceal the whole missing frame effectively. To resolve this problem, this paper proposes a new Adaptive Prediction Unit-based Motion Vector Extrapolation (APMVE) algorithm to restore the entire missing frame encoded by High Efficiency Video Coding (HEVC). In each missing HEVC frame, it uses the prediction unit (PU) information of the previous frame to adaptively decide the size of a basic unit for error concealment and to provide a more accurate estimation for the motion vector in that basic unit than can be achieved by any other conventional method. The simulation results showed that it is highly effective and significantly outperforms other existing frame recovery methods in terms of both objective and subjective quality.

***Keywords*:** Wireless networks, Error concealment, Motion vector extrapolation, HEVC, Prediction unit

1. Introduction

Many users are provided with video services in wireless networks. Although a size of video data is increasing gradually, high compression is essential to transfer over communication channels. Because highly compressed video data is more sensitive to channel errors than non-compressed video data, errors can occur in wireless transmission, which will degrade the entire video quality significantly. To reduce this effect, many error concealment algorithms have been proposed in various ways.

The HEVC standard is the newest joint video project of the ITU-T Video Coding Expert Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) standardization organization, working with in a partnership known as the Joint Collaborative Team on Video Coding (JCT-VC) [1]. The main goal of HEVC is a bit-rate reduction of 50% with similar video quality to H.264/AVC. Such considerably higher compression efficiency of the HEVC will potentially lead to packet loss, which will have a large impact on the users of portable devices, such as tablets and smartphones. In HEVC, each slice is encoded in a single network abstraction layer (NAL) unit. Each NAL unit of the HEVC stream is encapsulated in a single real-time transport protocol (RTP) packet using the RTP payload format for HEVC organized by Schierl et al. [2]. The multiple packet loss due to channel errors is more likely to occur than single packet loss in the wireless networks. In this situation, multiple packet loss results in a loss of an entire frame. Some conventional block-based concealment algorithms are not satisfied with whole frame concealment [3-5]. Therefore, it is essential to conceal the entire frame error.

Error concealment (EC) is an essential process to recover channel errors and several EC algorithms have been proposed. Some algorithms proposed a spatial EC using interpolation [3, 6-10], others exploited a temporal error concealment using MVE [11-15]. Spatial EC algorithms are inappropriate for concealing whole frame if the channel errors are spread to the entire frame. Although conventional MVE methods are suitable to conceal the entire frame, these methods have a drawback in their computational complexity or subjective quality.

Unlike existing video coding standards, such as H.264/AVC, one of the characteristics of HEVC is the more flexible block partitioning. The block structure of HEVC supports coding tree units (CTUs), a CTU is split into a quad-tree structure with four square coding units (CUs). Within the CU level, a prediction unit (PU) and a transform unit (TU) are composed to predict and transform, respectively. PU decides whether a corresponding CU is coding in intra or inter prediction mode. In the inter-prediction, a motion estimation and compensation are performed for a PU, meaning that the same object in a reference frame is likely to exist within the current PU.

This paper proposes an Adaptive PU-based Motion Vector Extrapolation (APMVE) method to increase the EC performance. The proposed approach consists of two stages: 1) Error Concealment Basic Unit (ECBU) decision, and 2) ECBU-based motion vector extrapolation for error concealment. In the first stage, an MV of every PU in the correctly received previous frame is extrapolated to a lost frame. To decide the ECBU size of the lost CTU, the relationship between the extrapolated PUs and the lost CTU is then considered. After the ECBU decision stage, the APMVE method is repeated to estimate the best MVs of the ECBU blocks in the lost CTU. Finally, an MV of a non-overlapped blocks (NOBs) is duplicated from an MV of a co-located PU in the corrected received frame.

The remainder of this paper is organized as follows. Section 2 briefly introduces the related works. Section 3 describes the proposed APMVE algorithm. Finally, the simulation results and conclusion are reported in sections 4 and 5, respectively.

2. Related Work

Some EC algorithms have been proposed to recover the entire frame loss during transmission. Chen et al. proposed a Pixel-based MVE (PMVE) method to recover a whole missing frame [15]. For each pixel in the lost frame, Chen's algorithm extrapolates an MV from the MVs of the previous reconstructed frame and the next frame. First, the pixels in the missing frame can be categorized into two parts: 1) For a pixel that is overlapped by at least an extrapolated macroblock (MB), its MV is estimated by averaging the MVs of all overlapped MBs. 2) For a pixel that is not covered by any of the extrapolated MBs, its MV is duplicated from the MV of the same pixel in the previous frame. On the other hand, the drawback of this algorithm is that the computational complexity is high because of the pixel-based MV determination.

Yan et al. proposed a Hybrid Motion Vector Extrapolation (HMVE) method based on PMVE, which uses the extrapolated MVs of the pixels and blocks [11]. This method first classifies the pixels in the missing frame into three parts: A, B, and C, as shown in Fig. 1. After reliable MV candidates in each pixel are rejected by a threshold, a final MV is then determined.

The abovementioned methods were implemented in H.263 and H.264/AVC, respectively. Alternatively, Lin et al. proposed a Motion Vector Extrapolation with Partition (MVEP) information that considers the partition decision information from the previous frame in HEVC [12]. The extrapolated blocks (EBs) were selected to a PU size,

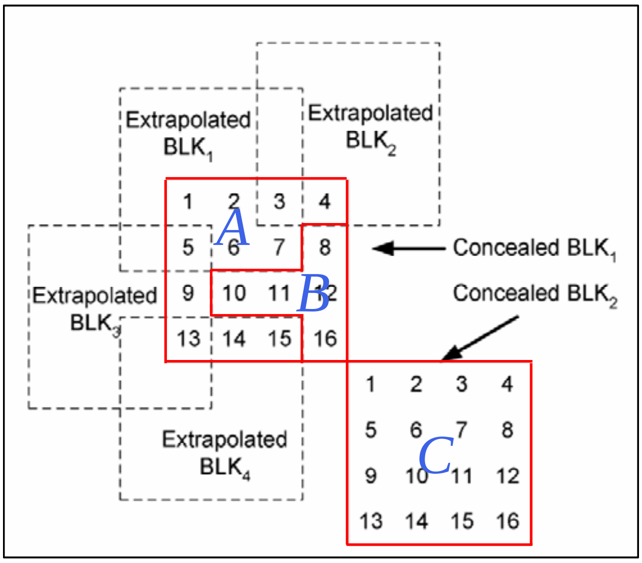


Fig. 1. Hybrid MV extrapolation (HMVE).

because this can to some extent indicate the object information. To obtain an MV in a missing frame, Lin's algorithm looks for both a larger overlapped area and a larger partition size to allocate higher priority to the MVs associated with a larger object.

3. The Proposed Algorithm

Although the MVEP algorithm takes advantage of the characteristics in HEVC, it still needs to overcome a drawback; the MVEP algorithm can degrade the subjective quality of a concealment frame because its error concealment basic unit (ECBU) is CTU, which is too rough to present a motion of video contents. An APMVE scheme, which uses the PU information of the previous frame for both the EB and ECBU decision, is proposed to overcome this drawback. This proposed algorithm can decide the ECBU of the lost CTU using the relationship between the extrapolated PUs and the lost CTU in the corrupted frame and assign an MV to each ECBU within the CTU.

3.1 ECBU Decision

In this algorithm, a PU size is exploited as an ECBU size. The PU is suitable for an EB because the same object likely exists in a PU that contains its motion information.

To decide an ECBU, MVE is performed for each PU of a previous frame. Fig. 2 gives an example of the PU-based MVE. The shaded CTU is being recovered. PU_{N-1}^{i} denotes the i^{th} PU in frame *N*–1, where *i* is 1 to *K*, and *K* is the total number of PUs in that frame. $MV(PU_{N-1}^{i})$ denotes the MV of PU_{N-1}^{i}. The extrapolated block of PU_{N-1}^{i} and its MV are denoted by EPU_{N}^{i} and $MV(EPU_{N-1}^{i})$, respectively. $MV(EPU_{N-1}^{i})$ can be obtained using Eq. (2).

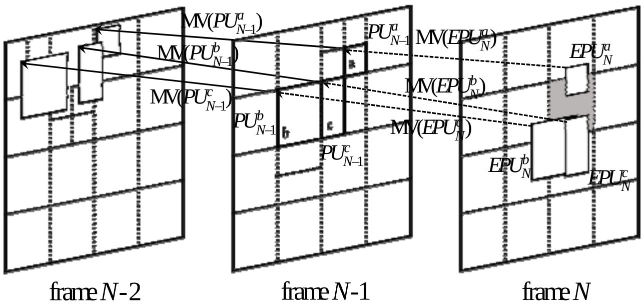


Fig. 2. Example of the PU-based MVE.

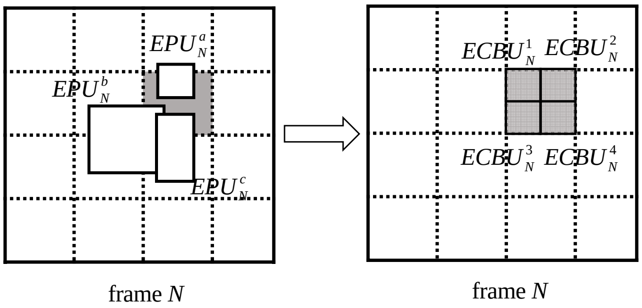


Fig. 3. Example of the ECBU decision in the lost CUT.

$$MV(EPU_N^i) = MV(PU_{N-1}^i), \quad (2)$$

where i is 1 to K. Some EPUs can be overlapped with the lost CTU. The MVs in the previous frame can be extended linearly to the current frame in MVE. Therefore, the lost CTU can be overlapped with various sized EPUs. In this paper, one of the overlapped EPUs is used to select the ECBU size of the lost CTU. To achieve the best quality, the smallest EPU size is selected as the ECBU size. On the other hand, if the ECBU size is very small, it is possible to cause block-artifacts in the concealed frame. The smallest ECBU size was restricted to $M \times M$ to overcome this problem. In other words, if the ECBU size is smaller than $M \times M$, it is changed to $M \times M$. Fig. 3 gives an example of the ECBU decision in the lost CTU. The lost CTU is divided into the size of EPU_N^a. Each block is denoted by $ECBU_N^j$, where j is 1 to L and L is the total number of $ECBU_N^j$.

3.2 ECBU-based Motion Vector Extrapolation for Error Concealment

To decide the MV of $ECBU_N^j$, which is defined by $MV(ECBU_N^j)$, we take advantage of the degree of overlap (the number of overlapped pixels) w_N^i between EPU_N^i and $ECBU_N^j$. w_N^i is given by

$$w_N^i = \sum_{p \in ECBU_N^j} f_N^i(p), \quad i = 1, \cdots, K \; and \; j = 1, \cdots, L, \quad (3)$$

where

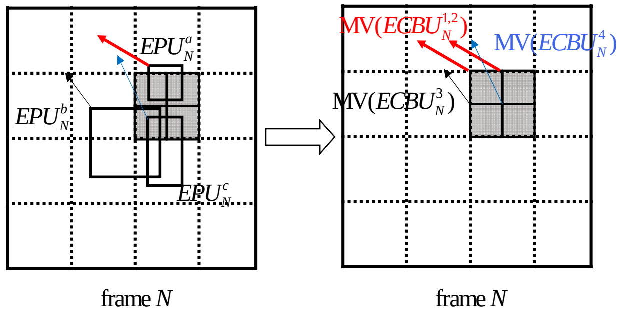


Fig. 4. Example of the MV estimation for the $ECBU_N^j$.

$$f_N^i(p) = \begin{cases} 1 & p \in EPU_N^i \\ 0 & p \notin EPU_N^i \end{cases}, \quad (4)$$

p is a pixel in the $ECBU_N^j$. The best $MV(ECBU_N^j)$ is then obtained by selecting the MV of the EPU with the maximum weight w_N^i. This is obtained as follows:

$$MV(ECBU_N^j) = MV(EPU_N^{i*}), \quad (5)$$

where

$$i* = \arg\max\{w_N^i\}, \quad (6)$$

Fig. 4 gives an example of the $MV(ECBU_N^j)$ estimation. Because EPU_N^a are overlapped with $ECBU_N^{1,2}$ the most, $MV(ECBU_N^{1,2})$ are set to $MV(EPU_N^a)$. In the same manner, $MV(ECBU_N^3)$ and $MV(ECBU_N^4)$ are applied to $MV(EPU_N^b)$ and $MV(EPU_N^c)$, respectively.

If $ECBU_N^j$ has not been overlapped by any EPUs, the MV of this block is duplicated from an MV of a co-located PU in the corrected received frame.

4. Simulation Results

The proposed APMVE method was simulated using the HEVC test model (HM) 11.0 and evaluated under the low-delay P configuration under a common test condition with some changes; The number of reference frames was 1 and asymmetric motion partitioning (AMP) was off. Two standard video sequences "BasketballDrill" and "BQMall" were used to evaluate the performance of the proposed algorithm. The frame rates were 50 frames/s and 60 frame/s, respectively. The frame size of both "BasketballDrill" and "BQMall" is 832×480 and quantization parameter (QP) was 32. In addition, the intra mode in P frame is disable when evaluating the accuracy of the results of APMVE method.

To decide the minimum ECBU size of the proposed method, an experiment was performed to select the optimal size among 4×4, 8×8 and 16×16. Fig. 5 shows the average PSNR values between the original sequence and the

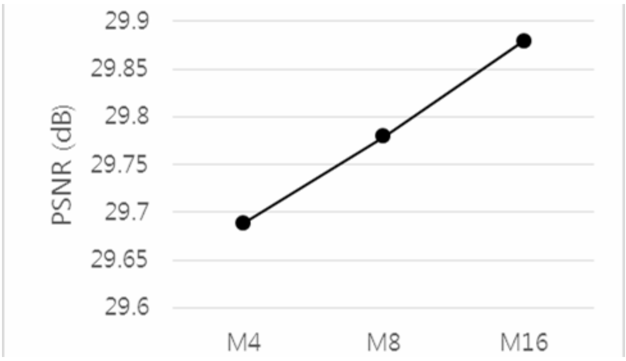


Fig. 5. PSNR value for "BQMall" sequence versus ECBU size.

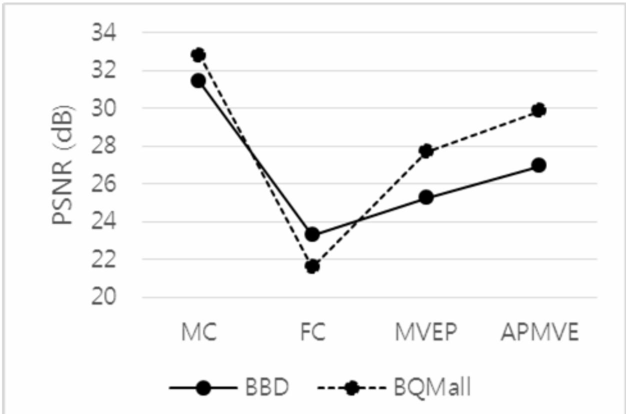
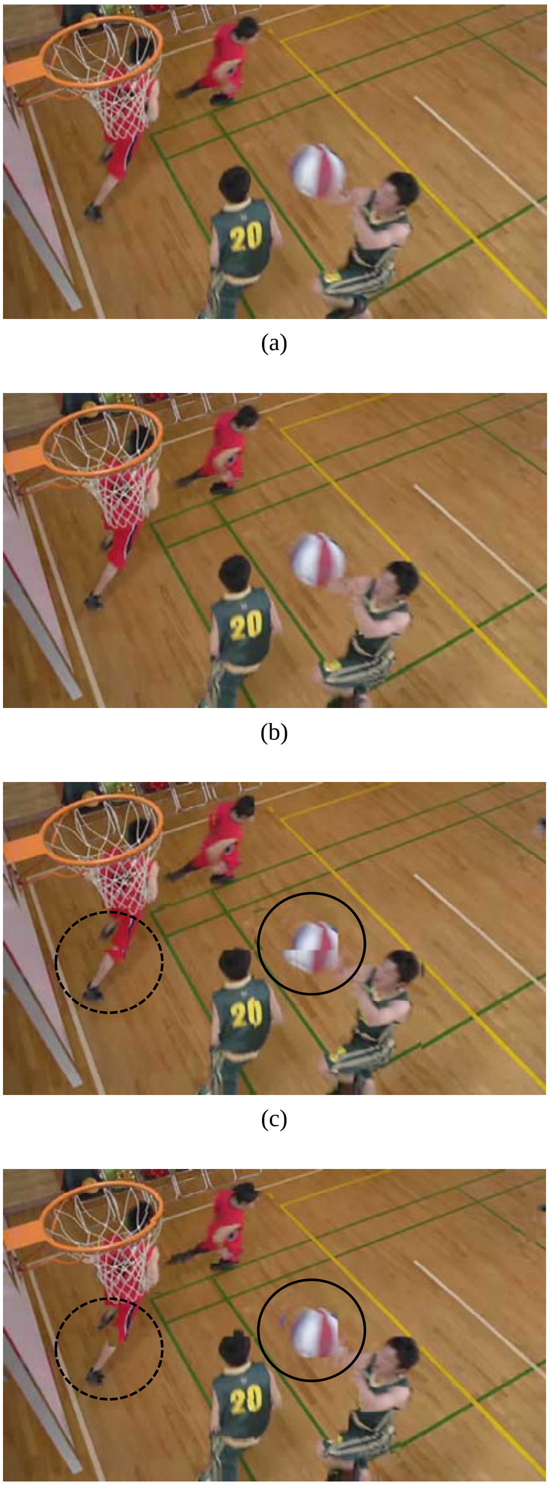


Fig. 6. PSNR quality of the EC algorithms for the "BasketballDrill" (BBD) and "BQMall" sequences.

concealed sequence according to the minimum ECBU sizes for the "BQMall" sequence. Whole frame loss occurs in every 15 frame in the original sequence. M_N denotes the minimum ECBU size of N. Although M_{16} produces similar performance to both M_4 and M_8 in the "BasketballDrill" sequence, M_{16} produces better performance than M_4 and M_8 in the "BQMall" sequence, as shown in Fig. 5, while providing similar results in the other sequences. Therefore, M_{16} is used as the minimum ECBU size.

To explain the effectiveness of the proposed method, the performance of the proposed APMVE algorithm was compared with that of the MVEP, frame copy (FC) and motion compensation (MC). FC means copying the previous frame for concealment. MC means that original MVs are received correctly, but residual information has been lost. As it is very difficult to estimate the MVs of a frame concealment than that of a block concealment, MC could be regarded as the upper bound. Fig. 6 shows the simulation results with PSNR for different test sequences. The proposed APMVE algorithm significantly outperformed FC and MVEP.

Figs. 7 and 8 show the results of one frame extracted from different sequences, where (a) is the error-free frame, and (b) to (d) are the images reconstructed using MC, MVEP and the proposed APMVE algorithm, respectively. Owing to the PU-based ECBU decision, the proposed APMVE algorithm can show good subjective quality,



(a)

(b)

(c)

(d)

Fig. 7. Restored 130th frame of "BasketballDrill" sequence with QP of 32 (a) error-free frame, (b) MC frame, (c) concealed with MVEP, (d) concealed with APMVE.

particularly around the edges of the image objects, as highlighted by the solid circles. In the "BasketballDrill" sequence, APMVE method conceals the basketball well, whereas MVEP generates a distorted sequence, resulting from an excessively rough ECBU size of the CTU.

(a) (b) (c) (d)

Fig. 8. Restored 34th frame of "BQMall" sequence with QP of 32 (a) error-free frame, (b) MC frame, (c) concealed with MVEP, (d) concealed with APMVE.

Although a PU represents an object's shape, APMVE method can estimate the wrong MV, as shown by dotted circles. This results from using a simple criterion, degree of overlap, in an MV estimation, which is sensitive to outliers. This limitation can be compensated for by other methods that focus on how to find the best MV [11, 14]. In addition, the MV of a non-overlapped block duplicated from a co-located MV can be improper. This block can be compensated for by a post-process, such as boundary matching algorithm and spatial-based error concealment algorithm.

5. Conclusion

This paper proposes a new EC algorithm, APMVE method, to conceal the whole missing frame encoded by HEVC. The PU information was used to adaptively decide the ECBU under the assumption that the same object likely exists in the PU. The MV of every PU in the correctly received previous frame is extrapolated to the lost frame. The temporal correlation between the extrapolated PU and the lost CTU was used to decide the ECBU. After the ECBU decision, the best MV of each ECBU in the lost CTU was estimated using degree of overlap and used for the lost frame concealment. The simulation results have showed that APMVE method provides better objective and subjective quality than the frame copy and MVEP method, particularly around the edges of the image objects.

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Seounghwi Kim was born in Seoul, Korea. He received his B.S. degrees in Electronic Engineering from Kwangwoon University, Seoul, Korea, in 2014. He is a Master student at the Kwangwoon University. His research interests are video processing, video compression, and video coding.

Dongkyu Lee was born in Seoul, Korea. He received his B.S. and M.S. degrees in Electronic Engineering from Kwangwoon University, Seoul, Korea, in 2012 and 2014, respectively. He is a PhD student at the Kwangwoon University. His research interests are image and video processing, video compression, and video coding.

Seoung-Jun Oh was born in Seoul, Korea, in 1957. He received both the B.S. and the M.S. degrees in Electronic Engineering from Seoul National University, Seoul, in 1980 and 1982, respectively, and the Ph.D. degree in Electrical and Computer Engineering from Syracuse University, New York, in 1988. In 1988, he joined ETRI, Daejeon, Korea, as a Senior Research Member. Later he was promoted to a Program of Multimedia Research Session in ETRI. Since 1992, he has been a Professor of Department of Electronic Engineering at Kwangwoon University, Seoul, Korea. He has been a Chairman of SC29-Korea since 2001. His research interests include image and video processing, video compression, and video coding