COMPRESSED IMAGE ERROR CONCEALMENT AND POSTPROCESSING FOR DIGITAL VIDEO RECORDING

Jen-Fwu Shen and Hsueh-Ming Hang

Department of Electronics Engineering
National Chiao Tung University
Hsin-Chu 300, Taiwan, R.O.C.

ABSTRACT

The recently developed MPEG video compression standards can compress motion pictures very efficiently; however, the compressed data are rather sensitive to channel noise. We therefore propose a robust decoder that can tolerate errors. Particularly, a two-priority coding scheme is suggested to increase the overall performance. This priority assignment can also be used to implement the trick playback mode for DVCR system. Moreover, an error concealment algorithm is proposed to compensate the cell loss effect due to random noise. Finally, the image artifacts due to undetected errors and/or imperfect error concealment can be reduced by a properly designed postprocessing scheme. As shown by simulations, damaged video sequences can be recovered almost free from visible artifact. Our study is different from the previous approaches in that we design a complete decoder system and the system is simulated in an environment that is close to reality.

1. INTRODUCTION

Digital video cassette recording (DVCR) receives a lot of attention recently since it can produce better quality video and audio and have more interactive functions than the existing analog VCRs. It is expected to be very popular for home use [1, 2]. For DVCR application, some unique requirements are imposed on the data compression scheme such as variable speed playback (or "trick" playback), which is not encountered in the other digital compressed video applications.

We use MPEG standard [3] as the basic coding scheme in our DVCR system, but our proposed processing algorithms can also be used for the other applications. In video recording, occasional periods of high error rate due to medium impairment can not be eliminated even when powerful error correction codes and large carrier-to-noise margins are designed into the recording systems. The impact of such bit-errors or cell-losses on the decoded video quality can be quite serious when popular motion compensated interframe prediction and variable length coding are used for compression. A single bit-error or data-loss event can propagate both spatially and temporally for a relatively long period of time until the refresh data are received.

Without errors the MPEG decoder receives the perfect variable-length coded bit stream and decodes the stream into a sequence of image frames. Unfortunately, the noise contaminated bit stream often fails an ordinary decoder. To solve this problem, we proposed a robust decoder which traces the decoded bit stream and can tolerate errors.

Then, we use an adaptive error concealment scheme to repair the damaged images. The basic principle of error concealment is to exploit the temporal or spatial redundancy of images. There are several error concealment methods that have been studied [4]. Our focus is more on how to use these concealment techniques cleverly together with the previous mentioned robust decoder.

Occasionally, error patterns are not detected and therefore the concealment scheme is not in act. Sometimes, the concealed images still have visible artifacts. In these cases, postprocessing may reduce the visibility of artifacts [5, 6]. Our experiments indicate that subjective quality of the error-concealed images can be further upgraded through our proposed postprocessor.

This paper is arranged as follows. Section 2 describes the entire system structure. Then, the noisy channel model for our DVCR system is described in Section 3. The proposed robust decoder, selective error concealment algorithm, and postprocessing algorithm are developed in Section 4. The performance of the overall system is evaluated in Section 5. Section 6 contains conclusions and discussions.

This work was supported by Industrial Technology Research Institute (ITRI), Taiwan.

2. SYSTEM OVERVIEW

The overall system block diagram is shown by Figure 1. It can be divided into several functional blocks as described below.

- **MPEG encoder:** This unit is a MPEG-I standard compatible encoder. In addition, it includes the specific functions proposed by our algorithms such as IBP group-of-pictures structure and data priority assignment. The net output bit rate is at about 6.5532 Mbps.
- **Transport encoder:** This unit packs the output data in accordance with the one-priority or two-priority coding formats. It inserts two sets of MPEG headers for two-priority coding: one for high priority data and the other for standard priority data.
- **Lossy channel model:** The noisy channel models are designed to emulate the real digital recording channel. Three noisy channel models are constructed. Model 1 is to simulate block damage due to scratches on the magnetic tape; Model 2 is to simulate byte damage due to dust cumulation or R/W error; and Model 3 combines the above two models together. Furthermore, error probability of channel is one of the simulation parameters and two values are tested. They are called

0-7803-2440-4/94/ $4.00 © 1994 IEEE

high noise channel and low noise channel. Details are described in Section 5.

• **Transport decoder:** The received video stream is checked first at the transport decoder to separate the legal codewords from the illegal ones. When an illegal codeword appears, an error token is attached to mark the erroneous macroblock. This transport decoder can also accept two-priority coding data format and can combine two fragmentary parts into a single one. After that, the decoded data are treated as those of one-priority data.

• **Robust MPEG decoder with error concealment:** The robust MPEG decoder is developed to process the received stream corrupted by noise because the standard MPEG decoder is fragile in processing noisy data. If error concealment is applied, system is switched to the delay decoding state. In such a way, we can accumulate more information to perform concealment on the current decoded macroblock.

• **Postprocessing unit:** The error-concealed picture quality can be further improved by this unit. Several types of artifacts, including mosaic pattern, false coloring, and blocking effect, can be reduced to increase the subjective picture quality.

3. PROPOSED DVCR ENVIRONMENT

3.1. IBP Coding Algorithm

We need a new data structure to meet the various DVCR playback requirements. It has been suggested that all the intraframes are arranged on a track for the trick playback purpose [7]. But the compression ratio is low. Therefore, we adopt a new scheme to increase the coding efficiency and still enable the trick playback modes. In MPEG syntax, several pictures constitute a group of pictures (GOP). They form an independent encoding and decoding unit. A typical GOP sequence is as follows:

I B B P B B P B B I B B P B B P......,

where 'I' denotes intraframe; 'P' denotes predicted frame; and 'B' denotes interpolated frame. Although, the inter-coded frames save a lot of bits in the coding process, its data can not be used to produce an independent image in the trick playback mode. Thus, we must increase intraframe data for this particular requirement. Therefore, in our proposal a GOP contains only three frames, 'IBP'. This structure is a reasonable compromise between the coding efficiency and the trick playback requirement [8].

3.2. Priority Coding

In the DVCR trick playback modes, the read/write heads do not cover all the tracks; therefore, the data, according to their locations on the track, can be separated into two kinds of priority, i.e., high priority (HP) data and standard priority (SD) data. We propose a priority assignment coding scheme based upon this observation. High priority data that will be retrieved in trick play modes must be independently decodable. Hence, they belong to the so-called independent decodable codes (IDC). In our arrangement, DC and low order AC transform coefficients of intra-coded frames are assigned to HP portion, while the rest of the transform coefficients are assigned to SP portion. We place the HP data on the path that read/write head can retrieve in the trick playback modes to increase the picture quality. In the normal playback, the priority assignment coding scheme has the same image quality as the single priority coding scheme.

4. PROPOSED DECODER SYSTEM

4.1. Robust Decoder

If we strictly follow the MPEG syntax, a couple of errors in coded bit stream can sometimes cause an MPEG decoder to fail. To overcome this problem, we enhance the robustness of the original decoder to combat noise. Our enhancement on the decoder is closely related with the transport decoding unit. It decodes data using the following rules.

1. If an illegal variable-length codeword is detected, the decoder skips the following bits until the next slice header is found. The error tokens are set in this period to mark the erroneous blocks.

2. Estimate the MBPS (macroblocks per slice) value of the damaged images based on the received data under the assumption that MBPS is nearly constant. This value is used as a reference for checking the legality of macroblock addresses when the macroblock address of the next slice header is decoded.

3. Check macroblock addresses and limit them to a reasonable range. For example, the macroblock address increment must be one for an intraframe slice. If the macroblock addresses are out of range, we set error tokens at these locations, and skip the following data until the next slice header is found.

4. Continue to decode a frame in spite of a missing picture header.

5. If end of file appears illegally, most image data which have been received are still decoded despite missing picture headers or sequence ending headers.

4.2. Selective Error Concealment Algorithm

We choose the elements in our error concealment algorithm after carefully comparing several existing schemes. In general, the temporal replacement schemes perform better than the spatial interpolation schemes when the video has no motion or slow motion. Spatial interpolation schemes often blur picture details, so they produce noticeable artifacts in the concealed images. But, if the video has high motion, the blurring effect is less noticeable to human eyes. Therefore, we adopt temporal replacement method when the corresponding image block of the previous frame is perfect. Spatial interpolation is used when no previous frame information is available.

Our proposed scheme, which is a combination of conventional techniques in a carefully arranged order, is stated below.

• **I-frame:** If the current I-frame video data are missing, the damaged region can be recovered from the previous P-frame according to the MPEG frame display order except for the first frame in a video sequence. We assume that the scene change does not appear often; hence, picture content would be almost the same in the previous and the current frame. We apply spatial interpolation only when the video data of the previous anchor frame in the corresponding region are lost.

Figure 2 shows the damaged macroblock under spatial concealment. The damaged macroblock '0' can be partially recovered from macroblock '1' and '2'. If macroblock '1' and '2' are both good, they are averaged to reproduce macroblock '0'. If either one of them is lost, we select the good one to replace macroblock '0'. In the worst case that macroblocks '1' and '2' are both lost, macroblock '0' is left as it is. Error concealment algorithm fails in such a severe data loss situation.

- **P- and B-frames:** The lost data of the P- or B-frames can be repaired by the video data of the previously undamaged I- or P-frame in the corresponding region. If the motion vector (MV) of the current damaged block is successfully received and an error token is present for the DCT coefficients, we can recover the lost block with the previous I- or P-frame data compensated with the received motion vector. The previous I- or P-frame data are stored in the frame memory and are used as an anchor frame when the motion vector and the error token of the current frame are received. But, if the current motion vector is lost, the lost motion vector can be replaced by the motion vectors of the upper block or the lower block. The motion vector of the upper macroblock is considered prior to that of the lower macroblock. This replacement idea based upon the fact that motion vectors of the adjacent blocks are very similar.

Our proposed error concealment system can run in two different modes: one-priority coding and two-priority coding. The most significant difference is the decoder has been enhanced to a robust decoder so that the decoding process is not interrupted due to damaged video signals. It also need one macroblock line delay to collect more information for the current decoding block. As for two-priority coding, HP data and SP data suffer from different levels of noises. This may be preferred as shown later.

Selective error concealment algorithm is base upon the following sequential processing order.

```
If (Intraframe)
   if ((First-frame) or (Error_token of anchor-frame))
       Spatial_Interpolation( );
   else
       Temporal_Replacement( );
else
   if ((Intra-coded macroblock) and
       (Error_token of anchor-frame))
       Spatial_Interpolation( );
   else
       Temporal_Replacement( );
```

For a particular block, either spatial concealment or temporal concealment is used, but not both. This is why this proposed algorithm is called "selective error concealment algorithm". It can provide rather good picture quality most of time, and is simple to implement as compared to the complicated conventional error concealment algorithms [4].

4.3. Postprocessing

Because error concealment can not provide perfect recovery of damaged images, we need extra processing to further improve the subjective quality of the decoded video. The image defects due to undetected errors or imperfect concealment are classified into the following three types. Then the defects can be reduced using the techniques described below.

1. **Mosaic pattern reduction:** Mosaic effect is due to AC coefficients loss in contiguous macroblocks and can be detected easily by checking all coefficients inside a macroblock. These macroblocks can often be recovered by using temporal replacement from the previous frame.

2. **False coloring reduction:** Sometimes, the color components of a macroblock are falsely decoded; therefore, the color of that slice is noticeably different from its lower and upper adjacent blocks. Hinted by this observation, we check the color component differences of adjacent pixels between two nearby macroblocks to decide whether this macroblock has false color. If it appears in contiguous blocks, the marked false color decoding areas are replaced from the preceding frame at the same location.

3. **Blocking effect reduction:** A 3×3 wide-band low pass filter is selected to reduce the effect of edge smearing. In order to preserve the sharpness of pictures, only four lines of pixels surrounding the to-be-processed block boundaries are processed with this low pass filter. The slight blocking effect due to temporal replacement is almost completely removed when scene has no or little motion and the serious blocking effect is reduced when the scene contains high motion.

The entire postprocessing system contains the above 3 steps and they are applied to images in sequel. After going through the proposed postprocessing, the error concealed and error pattern removed images are sent to the display.

5. SIMULATION RESULTS

5.1. Lossy Magnetic Channel Model

Lossy channel models are designed to simulate the real environment of the digital recording on magnetic media. Two assumptions are undertaken. One is that data be infected must byte aligned, and the other is that the number of error patterns is limited to the ones below. Two types of damages are assumed: block damage and byte damage. When a region of image data are lost or damaged, we call this situation as block damage. If the image data are damaged only on a spot, limited to a byte, it is called byte damaged. We assumed that an error pattern is only one byte long, and the combination is limited. Especially, error patterns can not to be the same as the prefix portion of the headers of sequence, GOP, picture, and slice, i.e. no 24 zeros in succession.

- **Block damage:** We take 1/8 track as a unit, called it "segment", and allow 16 kbytes video data per track to meet the capacity of magnetic tapes. We assume the read/write errors can be modeled as a two-state Markov-chain: the error free state and the erroneous state. The transition probability from one state to another is carefully chosen to match the practical system.

- **Byte damage:** In the first step, the number of damaged bytes in a track are selected randomly. In the second step, we select the location of the byte to be damaged randomly from the entire track. This process will continue until the total number of byte damage is completed.

Two set of error probabilities are used in simulation. They are listed in Table 1. Model 1 has block damage errors only and Model 2 has byte damage errors only. Model 3 has both. The initial states of Markov-chains are assumed to be error free.

5.2. Evaluation Measures

Two video sequences are selected as test images in our simulations. Each sequence is 30 frames long. The original video sources are encoded into bit stream and then the bitstream is fed into a noisy channel. We adopt the peak signal-to-noise ratio (PSNR) of the luminance component as the performance assessment for our proposed concealment and postprocessing algorithms. *Concealment gain* and *postprocessing gain* are is defined below. Subjective picture quality of simulated pictures is judged directly by human observers.

$$Concealment\_gain \equiv PSNR_{concealed} - PSNR_{damaged}.$$

$$Postprossing\_gain \equiv PSNR_{postprocessed} - PSNR_{concealed}.$$

5.3. Performance of Error Concealment Algorithm Alone

In this subsection, the reconstructed images are only processed by the proposed error concealment algorithm described in the previous sections. The performance of one-priority coding and that of two-priority coding are quite different. To resemble the noisy channel in reality, we choose Model 3 of lossy channel as simulation environment. The macroblock numbers per slice (MBPS) is a simulating parameter. Several MBPS values are tested. Two picture formats, CIF and CCIR, are simulated. Due to limited space, only CIF (352 pels × 240lines) pictures results are included. On the PSNR plots, "100 dB" means no channel error.

< One-Priority Coding >

Four values of MBPS are simulated to compare the concealed picture quality. We take the high noise case as examples. Figure 3 displays the PSNR of the damaged "Flowergarden" through high noise channel. Figure 4 shows the effectiveness of error concealment. The average PSNR and the concealment gain at of different MBPS is listed in Table 2.

From our simulation results, MBPS at about 15 is a good choice since it does not produce too much overhead and has very good concealment gain on the same pictures at the same bit rate. If MBPS is chosen to be equal to macroblock numbers per line (MBPS = 22 in this case), the performance is very unstable. It also produces uncomfortable subjective image defect.

< Two-Priority Coding >

In this coding scheme, IDC and DDC parts are impaired by noises with different probability. When the DDC data encounter high noise, the IDC data have low noise; when the DDC data encounter low noise, the IDC data are error free. This is under the assumption that the IDC data are protected a heavy error control code. Hence, the error probability of IDC data is lower. The bit rate of this scheme is almost the same with that of one-layer coding one. The bits ratio of IDC to DDC data is about 1:4 in our simulations.

The PSNR and concealment gain of the video sequence, "Flowergarden", are shown in Figure 5. Again, "100 dB" indicates perfect recovery (no error). They reveal that picture quality of the damaged images in two layer coding scheme is better than that in one layer coding scheme. Since the decoder can get more reliable information in two layer coding scheme, the error concealment does not need to do very much work.

5.4. Error Concealment plus Postprocessing

Since The concealed images are further processed through a postprocessor, the bit rate is the same as that described in the previous sections. The PSNR measurement does not always match to the real human visual perception. Typically, the PSNR improvement with postprocessing is about 1 dB with respect to the concealed results when additional errors are detected in our postprocessor. The pictures, however, demonstrate noticeably subjective quality improvement over the concealed images. One layer coding and two layer coding schemes are both simulated. To compare the results in numbers, we list the average PSNR improvement of various cases in Table 3. It can be seen that postprocessing improvement dependents upon the characteristics of the video sequences.

6. CONCLUSIONS

Although MPEG video coding standard is quite efficient and flexible, it suffers from channel noise particularly for the rather noisy DVCR channels. In this paper, we present a modified MPEG encoder, two DVCR channel models, an enhanced robust decoder, a selective error concealment algorithm, and a reliable postprocessor. The picture quality with the proposed scheme is significantly improved when data are damaged by channel noise.

The effectiveness of this scheme is not only owing to the individual elements in it but also owing to the complete system structure in which each element is designed to match each other. Previous studies often emphasize on one element of a complete system. For example, a well-tuned error concealment algorithm assumes all the errors can be detected from syntax, which is not true in practice. Thus, our simulations in this study are closer to how a real system could perform.

7. REFERENCES

[1] J. H. Lee, et al., "A study on new DCT-based bit rate reduction algorithm and variable speed playback for a home-use digital VCR," IEEE Trans. on Cons. Elec., Vol. **38**, No. 3, pp.236-242, August 1992.

[2] T. Noguchi, et al., "A home-use digital VCR with high density modulation method," IEEE Trans. on Cons. Elec., Vol. **38**, No. 3, pp.230-235, August 1992.

[3] Motion Picture Experts Group, (ISO-IEC/JTC1/SC2/WG11) CD-11172, Nov. 1991.

[4] H. Sun, K. Challapali and J. Zdepski, "Error concealment in digital simulcast AD-HDTV decoder," IEEE Trans. on Cons. Elec., Vol. **38**, No. 3, pp.108-118, August 1992.

[5] Y. S. Ho, and A. Gersho, "Classified transform coding of images using vector quantization," Intl. Conf. on ASSP, pp.1890-1893, Glasgow, Scotland, May 23-26, 1989.

[6] C.-N. Tien and H.-M. Hang, "Transform-domain postprocessing of DCT-coded images," *SPIE Visual Communications and Image Processing '93*, pp.1627–1638, Boston, USA, Nov. 1993.

[7] C. Yamamitsu, et al., "A study on trick plays for digital VCR," IEEE Trans. on Cons. Elec., Vol. **37**, No. 3, pp.261-266, August 1991.

[8] J.-B. Cheng, H.-M. Hang, and D. W. Lin, "An image compression scheme for digital video cassette recording," *1994 IEEE International Conference on Consumer Electronics*, Chicago, USA, June 1994.

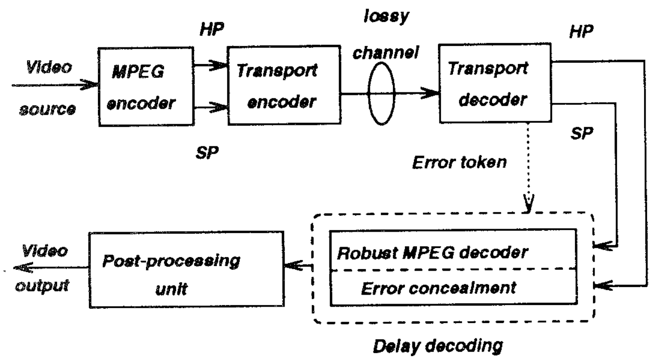


Figure 1: *The overall functions of MPEG-coded system for DVCR.*

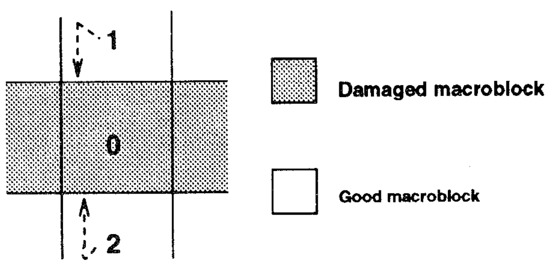


Figure 2: *Spatial interpolation for damaged macroblock.*

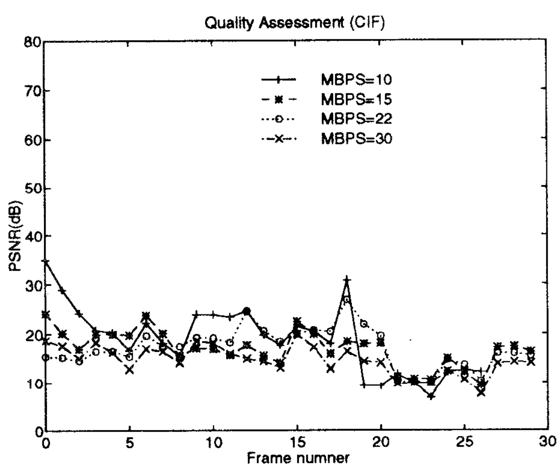


Figure 3: *PSNR assessment of damaged video sequence through high noise channel (Model 3) for Flowergarden (CIF) using one-priority coding scheme.*

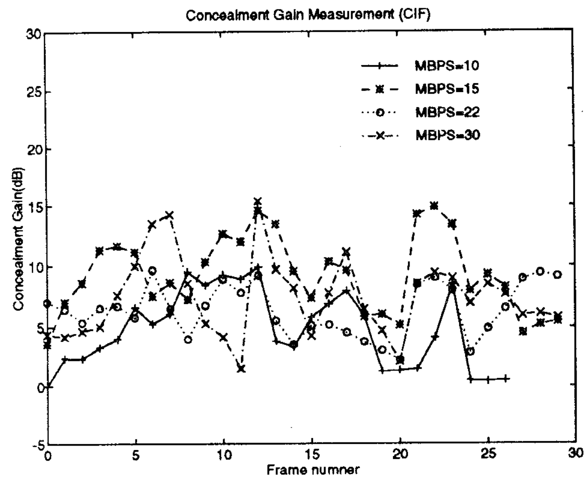
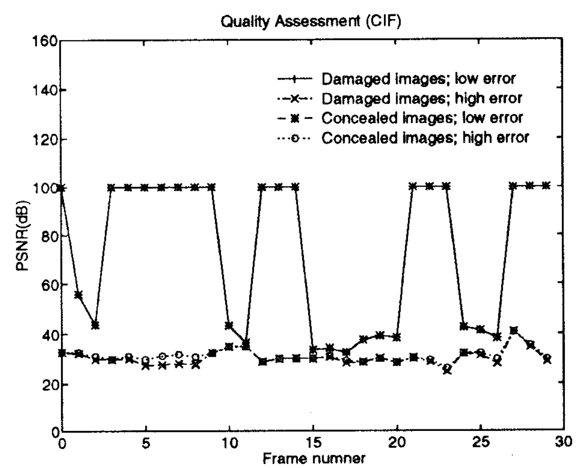
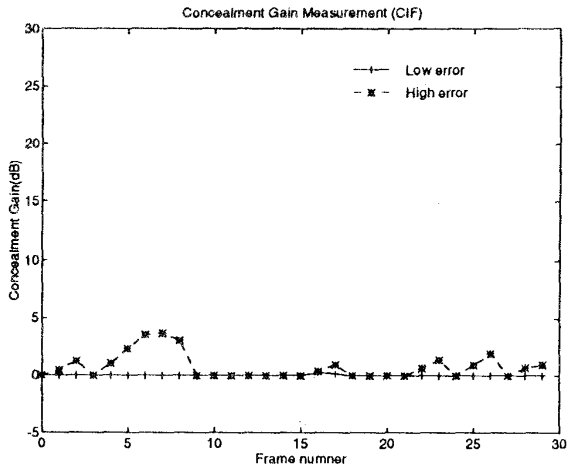


Figure 4: *Concealment gain of video sequence through high noise channel (Model 3) for Flowergarden (CIF) using one-priority coding scheme.*



(a) PSNR assessment.



(b) *Concealment gain after error concealment.*

Figure 5: *(a) PSNR assessment (b) Concealment gain of video sequence through noisy channel (Model 3) for Flowergarden (CIF), MBPS=15, in two-priority coding scheme.*

	Error Probability		
	Block damage (Model 1) Transition probability		Byte damage (Model 2)
	bad to good	good to bad	
High noise channel	0.99	0.01	8.33×10^{-5}
Low noise channel	0.995	0.005	4.16×10^{-5}

Table 1: *Noisy channel models.*

(unit:dB)	Low error rate			High error rate		
	PSNR (1)	PSNR (2)	Concealment gain	PSNR (1)	PSNR (2)	Concealment gain
MBPS=10	51.28	55.12	3.85	18.89	23.63	4.74
15	52.75	58.10	5.35	17.02	26.25	9.23
22	61.61	64.64	3.03	17.16	23.52	6.36
30	51.06	55.90	4.84	14.66	22.01	7.36

Table 2: *The average PSNR of (1)damaged images and (2)concealed images and concealment error of different MBPS for Flowergarden (CIF) through noisy channel (Model 1) in one layer coding scheme.*

(unit:dB)	One layer coding				Two layer coding			
	Flowergarden		Football		Flowergarden		Football	
	(2)only	(1)+(2)	(2)only	(1)+(2)	(2)only	(1)+(2)	(2)only	(1)+(2)
Low error	-0.003	5.35	0.000	5.42	-0.002	0.01	0.004	0.31
High error	-0.071	9.16	0.063	5.65	-0.046	0.73	0.035	2.74

Table 3: *(1)Concealment and (2)Postprocessing gain measurement (CIF)*