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Error Concealment Using a Data Hiding Technique for MPEG Video

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SUMMARY A new method of error concealment for MPEG videos, in which motion vectors are hidden in an MPEG bitstream as a watermark, is proposed in this paper. Several conventional methods conceal error regions by using motion vectors, which are re-estimated in a decoding process. These methods, however, have two problems: (1) The accuracy of a re-estimated motion vector is lower than that of an estimated motion vector in an encoding process. (2) A large amount of calculation is required to re-estimate motion vectors. The proposed method overcomes these problems by using hidden accurate motion vectors. That is, it hides several bits in each 8×8 DCT block of all frames and, simultaneously, inhibits the image degradation caused by hiding motion vectors. In addition, it has upward compatibility with a standard MPEG decoder and can be combined with conventional methods. Simulation results show that the accuracy of error concealment by the new method is higher than that of the conventional methods.

key words: *MPEG, error concealment, watermarking, data hiding*

1. Introduction

The importance of video communication through mobile telecommunication networks has recently been increasing. Since these networks transmit data at a relatively high bit error rate, some regions of the transmitted video data may not be decoded. Therefore, the quality of the decoded video images is degraded.

To handle such a degradation, error concealment methods have been proposed for MPEG video [1]–[7]. Three tools, namely, resynchronization, data recovery and error concealment are known as error resilience. The error concealment is useful for concealing loss packets and errors that other tools cannot conceal.

There are two types of the conventional methods for error concealment: those that do not use motion vectors and those that do. It is known that the latter methods are superior to the former ones in concealing error regions. The latter, however, must re-estimate motion vectors, which needs a large amount of calculation. Consequently, the hardware decoder consumes much electric power. In addition, the accuracy of re-estimated motion vectors in a decoding process is lower than that of estimated motion vectors in an encoding process. Especially, it is difficult to obtain the high accuracy of re-estimated motion vectors in frames with burst errors.

In light of the above problems, we propose a novel method for error concealment that hides motion vectors in an MPEG bitstream. This method is categorized as one that uses motion vectors (i.e., a conventional method). In this method, motion vectors estimated in an encoding process are hidden in each video frame and are used for error concealment. Consequently, accurately estimated motion vectors are obtained in a decoding process without re-estimation even if the error rate is high. Furthermore, the proposed method has upward compatibility with a standard MPEG video decoder and, simultaneously, can be combined with conventional error concealment methods. As the data hiding technique, an extended version of the methods previously proposed by the authors [8]–[10] is employed. While several bits are hidden in each 8×8 DCT block, the image deterioration is inhibited by this technique.

The organization of this report is as follows. Section 2 reviews conventional methods for error concealment and their problems. In Sect. 3, the error concealment method for MPEG video is proposed. Section 4 shows the results of some simulations of the proposed method.

2. Conventional Methods for Error Concealment [1]–[5]

Conventional error concealment methods and their problems are summarized in this section.

2.1 Methods without Motion Vectors

There are two types of methods for error concealment without using motion vectors: those that copy the corresponding blocks from the reference frame and those that interpolate between the circumferential pixels of the error regions in the current frame.

Figure 1 shows an example of the former method, where the dark region in the current frame represents an error block that completely misses information. In these methods, a block in the reference frame is copied onto the same position as the error block in the current frame. The amount of calculation involved in

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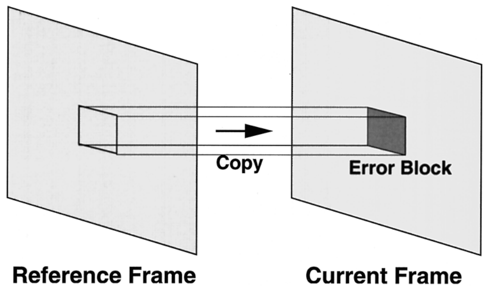


Fig. 1 Block copy without using motion vectors.

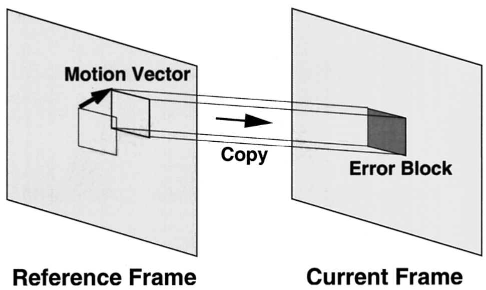


Fig. 2 Block copy with a motion vector.

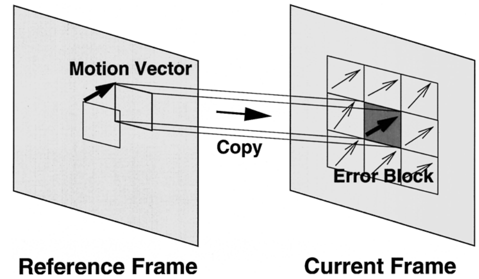


Fig. 3 Motion estimation using motion vectors in the blocks around an error block.

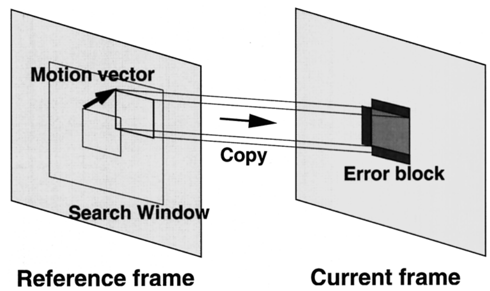


Fig. 4 Motion estimation using the BMA.

these methods is small, because there is no need to re-estimate motion vectors. The quality of error concealment is, however, degraded when the error part has a movement.

On the other hand, interpolation methods interpolate between decoded pixels around the error region. If there is an edge of an object in the error part, the quality of the concealed image is degraded.

2.2 Methods with Motion Vectors

An example of a method using motion vectors is shown in Fig. 2. In this figure, the dark region in the current frame represents an error block, and the arrow in the reference frame is a re-estimated motion vector. In this method, a block indicated by the re-estimated vector in the reference frame is copied onto the error block in the current frame. Since the quality of error concealment depends on the accuracy of re-estimated motion vectors, this method requires an algorithm that accurately re-estimates motion vectors.

These methods use two algorithms for re-estimating motion vectors. One estimates a new vector from the motion vectors in the blocks around an error block. The other estimates a new vector by using the accurately decoded pixels of the circumferential blocks. Figure 3 shows the former methods using motion vectors. Thin arrows represent motion vectors in the blocks around an error block. The fat arrow is the motion vector that is re-estimated by using the vectors of the blocks. When the direction of the movement of the error block differs from that of the circumferential blocks, the quality of error concealment is degraded.

Figure 4 shows the BMA (Boundary Matching Algorithm) [2], as an example of the latter methods. The algorithm selects a new motion vector that has the minimum total squared difference between the block in a reference frame and the surrounding pixels of the error block. Since this algorithm estimates new motion vectors from pixel values, it requires a huge amount of calculation.

3. Proposed Method

The error concealment method for MPEG video that employs a data hiding technique is proposed in this section.

3.1 Amount of Hidden Data

An accurate motion vector is hidden in each 16×16 macro block in the encoding process in order to improve the quality of error concealment. The number of bits embedded in a DCT block, N, is estimated in this section. One motion vector and one identifier for classifying frames, which are I (Intra coded), P (Predictive coded), and B (Bidirectionally predictive coded), are required for each macro block.

For example, if a search-window size is set to $w = \pm 15$, the required data consists of two bits for the identifier and 10 bits for the motion vector. Total 12 bits are required for each macro block and three bits ($N = 3$) are hidden in each 8×8 DCT block. It is noted that the values of motion vectors are directly embedded without using variable-length coding. If the hidden motion vectors of the lower accuracy is used, the smaller bits ($N < 3$) may be hidden in the bitstream.

3.2 Methods of Hiding Data

Figure 5 is a block diagram of the extended MPEG encoder that hides motion vectors in a video bitstream. The dark squares represent the differences from a standard MPEG encoder. Figure 6 describes a block diagram of the MPEG decoder which can extract hidden motion vectors. The dotted-line arrow represents the flow of hidden motion vectors, which a standard MPEG decoder does not use or require.

Methods of hiding data in JPEG and MPEG images have already been proposed [8]–[10]. However, in these methods, only one-bit data is hidden in each 8×8 DCT block and data is not hidden in P nor B frames. Since it is considered that a large amount of data is hidden in each block in all frames, as mentioned in Sect. 3.1, these methods are extended in this section.

The followings are required to hide motion vectors in images:

(a) Precious extraction of the hidden data
(b) Inhibition of image deterioration.

To extract the hidden data precisely, the data is hidden in quantized DCT coefficients. A coefficient is chosen from 64 coefficients in a DCT block in order to hide N bits ($N = 3$ in this paper), and the magnitude of a chosen coefficient is replaced by hidden N bits data. The chosen coefficient is $QDCT(63)$, where $QDCT(p)$ represents the p-th quantized DCT coefficient of the zigzag scanned sequence. Thus, this proposed method hides data in the highest frequency coefficient of each DCT block. To inhibit the image deterioration caused by hiding the data, a modified quantization table is employed in the decoding process. The values of the quantization table corresponding to the chosen coefficient is replaced by '1,' as shown in Table 1.

3.3 Method of Concealing Error

In the concealment process, the error regions are concealed by using the hidden motion vectors. Blocks corresponding to hidden motion vectors in the reference frame are copied onto the error blocks. Consequently, re-estimation of the motion vectors is not required. This proposed method use the accurately estimated motion vectors so that the quality of error concealment is improved.

Since intra frames do not have motion vectors in MPEG encoders, the method cannot be used for error concealment in these frames. If motion vectors in intra frames are generated in the same way as predictive coded frames, these vectors can be hidden in an MPEG bitstream. If motion vectors in intra frames are not generated in these frames, conventional methods,

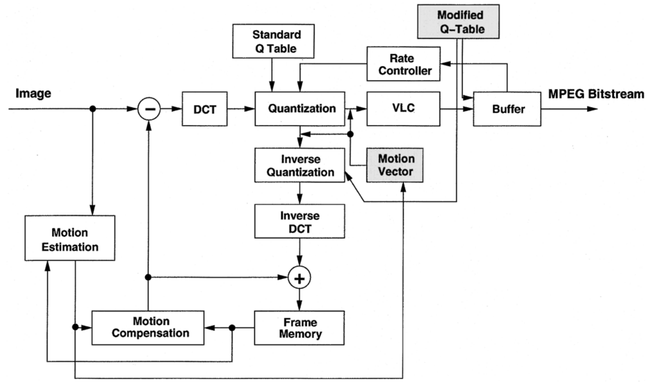


Fig. 5 Block diagram of an extended MPEG encoder which hides motion vectors.

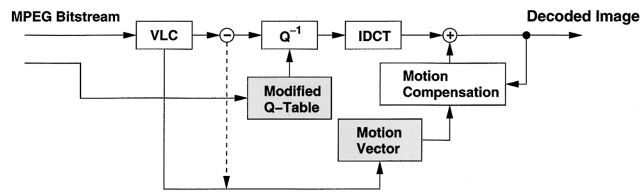


Fig. 6 Block diagram of an extended MPEG decoder which can extract hidden motion vectors.

Table 1 Modified quantization table.

8	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	1

such as block copy and interpolation methods, are used for error concealment in intra frames.

The proposed method has a large degree of freedom to select a macro block in which a motion vector is hidden. It is considered that data is hidden in the corresponding place in the reference frame or other blocks in the current frame. The location of the block where the data is hidden is chosen according to the robustness against errors and the complexity of the hiding process. When embedded motion vectors cannot be extracted from a bitstream, however, error blocks are concealed by using conventional methods, since the proposed method can be combined with the conventional methods.

It should be noted that a standard decoder is available for decoding bit streams produced by the proposed encoder in Fig. 5. A modified quantization table is used to avoid image degradation in the standard decoder.

4. Performance Evaluation

Performance of the proposed method is investigated by

Table 2 Simulation conditions.

Image	Flower Garden, Football	Carphone
Frame size	704 × 240	176 × 144
Target rate	10 M, 5 M, 1 M [bps]	1 M, 512 k, 256 k [bps]

some simulations.

4.1 Conditions

Three grayscale video sequences, "Flower Garden," "Football" and "Carphone" are employed for evaluation of the new error concealment method. These sequences are encoded by an MPEG-1 algorithm within the MPEG-2 software encoder [11]. Conditions of each sequence are described in Table 2. As the encoding parameters, it is assumed that the GOP consists of nine frames and the distance between the I frame and the P frame is three. The search-window size is set to $w = \pm 15$ and 3 bits are hidden in each DCT block, as described in Sect. 3.1.

In P and B frames, the motion vector of each macro block is embedded into another macro block in the frame where forward motion vectors are selected as hidden data in B frames. In I frames, any motion vectors are not embedded because they are not calculated in an MPEG encoder.

The quality of images is evaluated by the PSNR (Peak Signal-to-Noise Ratio) defined as

$$PSNR = 10 \log_{10} \frac{ImageSize \times 255^2}{\sum_{i=1}^{rows} \sum_{j=1}^{cols} \{p(i,j) - f(i,j)\}^2} \text{ [dB]},$$

where $p(i,j)$ and $f(i,j)$ represent a luminance of the pixel before the compression and that after decoding, respectively.

4.2 Image Deterioration by Hiding Motion Vectors

The image quality produced as a result of hiding motion vectors was evaluated using a standard MPEG decoder. Since three bits are hidden in each DCT block as described in Sect. 3.1, 7920 bits (990 bytes) are hidden in one frame (704 × 240 pixels) in this evaluation.

Figure 7 shows the image deterioration; that is the frame-by-frame reduction in PSNR when hiding motion vectors by using three different methods. We can see that the data hiding method with modified table described in Sect. 3.2 gives the nearest PSNR values to those of the standard MPEG video, indicated as no hidden in Fig. 7. The PSNR produced by this method is 0.5 [dB] lower than that produced by the standard MPEG video at the worst frame. On the other hand, when using the method without modified table is used, the PSNR of the image deteriorates by 1 to 8 [dB].

The conventional method [12]–[14] in Fig. 7 is a method that hides three bits in each 8×8 DCT block by replacing the LSB of three low frequencies coefficients. The PSNR produced by this conventional method is about 4 [dB] lower than that produced by the proposed method with modified table, except for intra frames.

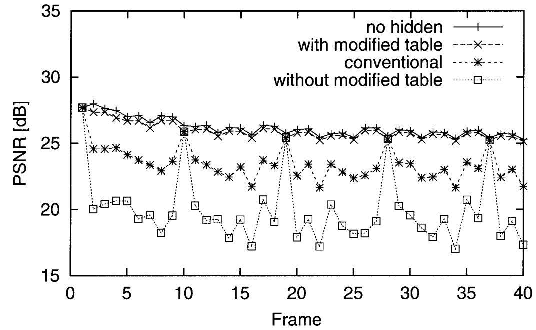


Fig. 7 Image deterioration by hiding motion vectors (Flower garden).

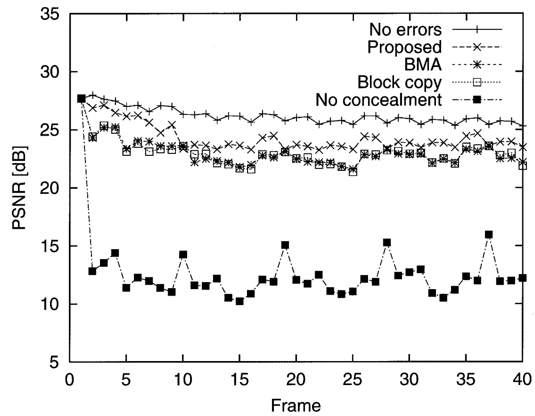


Fig. 8 Quality of error concealment (Flower garden 1 [Mbps]).

These results show that modifying the quantization table is effective in inhibiting image degradation by hiding motion vectors.

4.3 Quality of Error Concealment

The quality of error concealment is discussed in this section. It is assumed that error macro blocks are generated randomly and independently at the rate of 10^{-1}. The proposed method is compared with the block copy method and the BMA. Figures 8, 9 and 10 represent the quality of the error concealed image, where "no errors" means the quality of the images using the standard MPEG video without error blocks, "no concealment" shows that of images with error blocks, as in Figs. 11 and 12 and vertical linear interpolation was used for error concealment of intra frames in the proposed method. Tables 3, 4 and 5 are the average PSNR values of 64 error concealed frames.

From Tables 3, 4 and 5, we can see that the proposed method improves the PSNR values of concealed images compared to the conventional methods except for at 256 [kbps] in Table 5. The results at 256 [kbps] show that PSNR values are strongly influenced by hiding motion vectors, when the bit rate is low. Please note that the proposed method and the BMA give more natural images than other conventional methods even in low-bit rates, as shown in Figs. 13 and 14 where these images correspond to the square areas in Figs. 11 and 12 respectively. Moreover, the proposed method does not need a large amount of calculations to re-estimate motion vectors, which the BMA needs, in a decoding process.

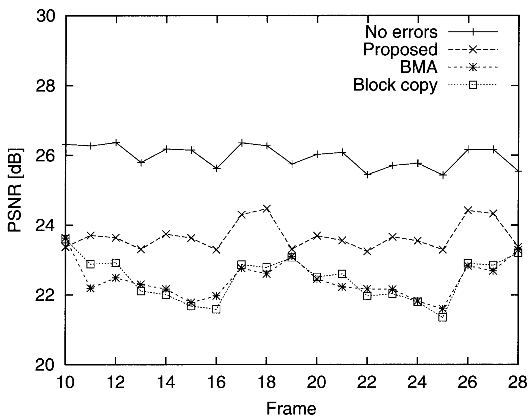


Fig. 9 Quality of error concealment (Flower garden 1 [Mbps]).

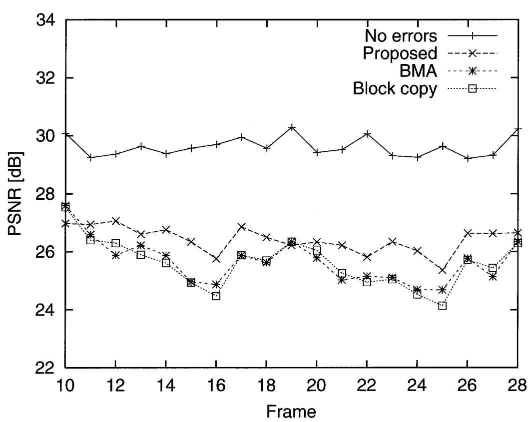


Fig. 10 Quality of error concealment (Football 1 [Mbps]).

5. Conclusions

A new method for error concealment in MPEG video by using data hiding has been developed. This method

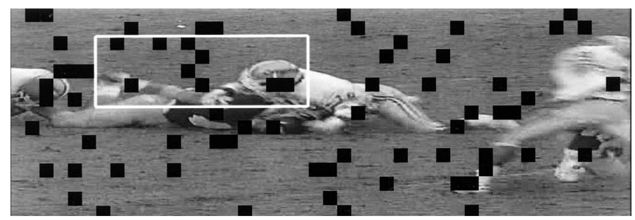


Fig. 11 Error macro blocks generated independently (Football 1 [Mbps]).

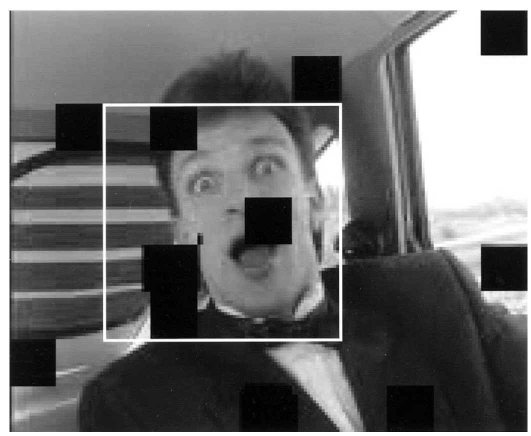


Fig. 12 Error macro blocks generated independently (Carphone 256 [kbps]).

Table 3 Average PSNR of concealed images (Flower garden).

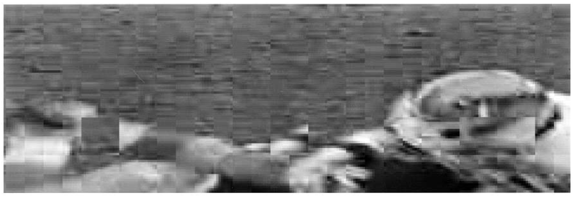
Rate[bps]	No errors	Proposed	BMA	Block copy	Interpolation	No concealment
10 M	40.828765	27.076681	24.144302	24.083881	23.430412	12.373671
5 M	35.510902	26.558068	23.938618	23.902919	23.308632	12.348975
1 M	26.000105	23.949374	22.794832	22.692808	22.138289	12.213266

Table 4 Average PSNR of concealed images (Football).

Rate[bps]	No errors	Proposed	BMA	Block copy	Interpolation	No concealment
10 M	42.127148	30.545060	27.394991	27.155228	27.643388	14.015950
5 M	37.289573	29.766346	27.027278	26.831167	27.291605	14.001531
1 M	29.525940	26.394333	25.742528	25.372884	25.777637	13.817676

Table 5 Average PSNR of concealed images (Carphone).

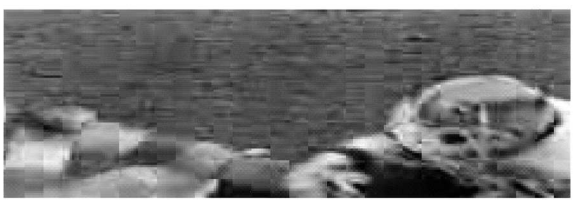
Rate[bps]	No errors	Proposed	BMA	Block copy	Interpolation	No concealment
1 M	51.454751	44.225738	40.579713	42.270801	35.696754	21.540706
512 k	47.615948	42.631951	40.087540	41.447995	35.506497	21.452673
256 k	43.903157	38.911028	38.969218	40.189499	35.265660	21.392633



(a) Block copy method

(b) Interpolation method

(c) Boundary matching algorithm



(d) Proposed method

Fig. 13 Images of error concealment (Football 1 [Mbps]).

hides estimated motion vectors in video frames in an encoding process and errors are concealed by using these hidden motion vectors in a decoding process. The proposed method can therefore retrieve accurate motion vectors without having to re-estimate vectors which requires a large amount of calculation. In addition, this method is compatible with a standard MPEG decoder and can be conventional error concealment methods to combine with.

Simulation results show that the image deterioration caused by hiding motion vectors is small, even though about 1000 bytes are hidden in every frame. Furthermore, it was found that the proposed method is superior to the conventional methods.

We plan to consider the quality of proposed error concealment on an MPEG-4 video algorithm [15] in more detail as a future work.

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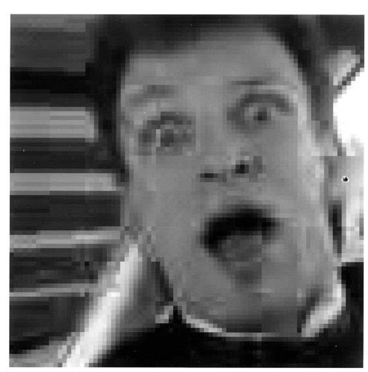
(a) Block copy method

(b) Interpolation method

(c) Boundary matching algorithm



(d) Proposed method

Fig. 14 Images of error concealment (Carphone 256 [kbps]).

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References

[1] A.K. Katsaggelos, F. Ishitiaq, L.P. Kondi, M.-C. Hong, M. Banham, and J. Braiean, "Error resilience and concealment in video coding," Proc. IX European Signal Processing Conference, pp.221–228, Rhodes, Greece, Sept. 1998.
[2] W.M. Lam, A.R. Reilbman, and B. Liu, "Recovery of lost or erroneously received motion vector," Proc. IEEE International Conference on Acoust., Speech & Signal Process., vol.5, pp.417–420, April 1993.
[3] J.W. Park, J.W. Kim, and S.U. Lee, "DCT coefficients recovery-based error concealment technique and its application to the MPEG-2 bit stream error," IEEE Trans. Circuits Syst. Video Technol., vol.7, no.6, pp.845–854, June 1997.
[4] P. Salama, N.B. Shroff, and E.J. Delp, "Error concealment in MPEG video streams over ATM networks," IEEE J. Sel. Areas Commun., vol.18, no.6, pp.1129–1144, June 2000.
[5] H. Song, T. Song, H. Okada, G. Fujita, T. Onoye, and I. Shirakawa, "An error concealment algorithm using motion estimation method for MPEG-4 video," IEICE Technical Report, DSP2000-107, Oct. 2000.
[6] M. Kurosaki and H. Kiya, "Error concealment using data hiding technique for MPEG video," The 14th Workshop on Circuits and Systems in Karuizawa of IEICE, pp.71–76, April 2000.
[7] T. Kimoto and Y. Miyamoto, "Adaptive switching method in error concealment," IEICE Gen. Conf. '00, no.D-11-26, p.26, April 2000.
[8] H. Kiya, Y. Noguchi, A. Takagi, and H. Kobayashi, "A method of inserting binary data into MPEG bitstreams for video index labeling," Proc. 1999 IEEE International Conference on Image Processing.
[9] Y. Noguchi, H. Kobayashi, and H. Kiya, "A method of extracting embedded binary data from JPEG bitstreams using standard JPEG decoder," IEICE Trans. Fundamentals, vol.E83-A, no.8, pp.1582–1588, Aug. 2000.
[10] H. Kiya, "Methods for embedding binary data into JPEG and MPEG images in the compressed domain," IEICE Trans. Fundamentals (Japanese Edition), vol.J83-A, no.12, pp.1349–1356, Dec. 2000.
[11] MPEG Software Simulation Group, "MPEG-2 encoder/decoder version 1.2," [Online] Available WWW: http://www.mpeg.org/MPEG/MSSG
[12] K. Matsui, Image hidden code? A method and application, pp.139–147, Morikita-publisher, 1993.
[13] K. Matsui, A basic of digital watermarking? A new protection technique of multimedia, pp.57–60, Morikita-publisher, 1998.
[14] T. Kataoka, K. Tanaka, Y. Nakamura, and K. Matsui, "Embedding a document into color picture data under adaptive discrete cosine transform coding," IEICE Trans. Commun. (Japanese Edition), vol.J72-B-I, no.12, pp.1210–1216, Dec. 1989.
[15] ISO/IEC 14496-2:1999/Amd.1:2000 "Information technology—Generic coding of audio-visual objects—Part 2: Visual," International Standard.

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