

True Motion Vectors for Robust Video Transmission

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ABSTRACT

In this paper, we make use of true motion vectors for better error concealment. Error concealment in video is intended to recover the loss due to channel noise by utilizing available picture information. In our work, we do not change the syntax and thus no additional bits are required. This work focuses on improving the error concealment with transmitted true motion vectors. That is, we propose a “true” motion estimation at the encoder while using a post-processing error concealment scheme that exploits motion interpolation at the decoder. Given the location of the lost regions and various temporal error concealment techniques, we demonstrate that our true motion vectors perform better than the motion vectors found by minimal-residue block-matching. Additionally, we propose a new error concealment technique that improves reconstruction quality when the previous frame has been heavily damaged. It has been observed that in the case of a heavily damaged frame, better predictions can be made from the past reference frame, rather than the current reference frame which is damaged. This is accomplished by extrapolating the decoded motion vectors so that they correspond to the past reference frame.

Keywords: Motion estimation, neighborhood-relaxation motion estimation algorithm, true motion tracker, error concealment, robust video transmission.

1. INTRODUCTION

Error concealment in video is intended to recover the loss due to channel noise, e.g., bit-errors in a noisy channel and cell-loss in an ATM network, by utilizing available picture information. The error concealment techniques can be categorized into two classes according to the roles that the encoder and the decoder play in the underlying approaches. Forward error concealment includes methods that add redundancy in the source to enhance error resilience of the coded bit streams. For example, I-picture motion vectors were introduced in MPEG-2 to improve the error concealment. However, a syntax change is required in this scheme. In contrast to this approach, error concealment by post-processing refers to operations at the decoder to recover the damaged images based on image and video characteristics. In this way, no syntax is needed to support the recovery of missing data.

In our current work, we do not rely on the syntax, but focus on post-processing methods for data recovery. These post-processing methods are based on the finding true motion vectors at the encoder. Using the true motion vectors for video coding can reduce the bit rate for residue information and motion information,¹ and coding true motion vectors offers significant improvement in motion-compensated frame-rate up-conversion over the minimal-residue block-matching algorithm (BMA). This has been shown in our previous work, where it has been asserted that accurate motion estimation yields noticeably better frame-rate up-conversion results.² Because the error concealment problem is similar to the frame-rate up-conversion problem when the error is the whole frame, we can also interpolate the damaged image regions better with help from true motion vectors.

In general, there are two key components in error concealment: (1) an appropriate transport format which helps to identify picture regions which correspond to lost or damaged data, and (2) a spatial- and/or temporal- interpolation technique to fill the lost picture elements. In this paper, we focus our energy on the second point. We discuss concealment techniques that focus on improving a given block of data using information from available frames which have already been decoded. Our objective is to demonstrate the strength of transmitting motion vectors derived from our neighborhood-relaxation motion estimation algorithm. For completeness, the highlights of this algorithm are reviewed in the next section. It should be noted that we do not identify the image regions that correspond to lost video data. Given the location of the lost regions, we use a specific temporal error concealment algorithm to compare different motion estimation algorithms. In Section 3, the proposed algorithm for error concealment will be discussed. Then in Section 4, the results of various simulations will be presented. The types of error condition that are simulated include missing motion vectors, missing motion vectors and residue, and the previous frame being

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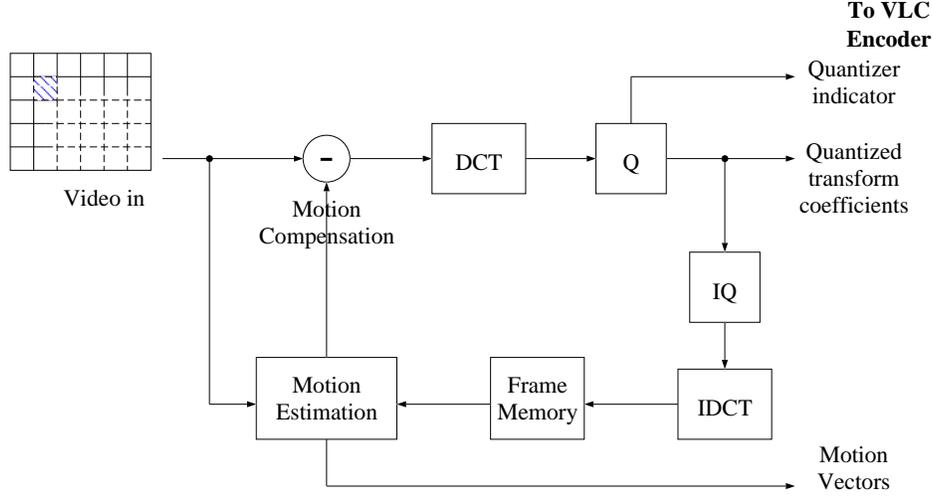


Figure 1. A generic MPEG-1 and MPEG-2 encoder structure is shown here. There are two basic components in video coding. The first one is the discrete cosine transform (DCT) which removes spatial redundancy in a static picture. Another one is motion estimation which removes temporal redundancy between two consecutive pictures. When the encoder receives the video, motion estimation and motion compensation first remove the similar parts between two frames. Then, DCT and quantization (Q) remove the similar parts in the texture. These quantizer indicators, quantized transform coefficients, and motion vectors are sent to a variable length encoder (VLC) for final compression. Note that the better the motion estimation, the less the work to be done in the DCT. That is to say, the better the motion estimation, the better the compression performance.

heavily damaged. For this last case, a new method of error concealment is proposed. In this method, we draw our attention to the quality of the next frame after the damaged frame, rather than the damaged frame itself. Finally, the conclusions of this work are summarized in Section 5.

2. NEIGHBORHOOD-RELAXATION MOTION-ESTIMATION AT THE ENCODER

In this section, our true motion tracker (TMT) for obtaining the true motion vectors in a block-based video sequence is reviewed.^{1,3} The approach is based on neighborhood relaxation techniques.

In order to minimize the amount of information to be transmitted, block-based video coding standards, such as MPEG and H.263, encode the displaced difference of a block instead of the original block (see Figure 1). For example, a block in the current frame, $B_i(t)$, is similar to a displaced block in the previous frame, $\tilde{B}_i(t-1, \vec{v})$. The residue block, $R_i(t)$, is equal to the difference, $B_i(t) - \tilde{B}_i(t-1, \vec{v})$, and is coded together with the motion vector, \vec{v} . Since the actual compression ratio depends on the removal of temporal redundancy, conventional BMAs use minimal-residue as the criterion to find the motion vectors.⁴

The above can be summarized in the following three steps, where the quantized DCT coefficients and differentially encoded motion vectors are then transmitted to the decoder:

- Motion Estimation: A block $B_i(t)$ at time t finds a \vec{v} -displaced block $\tilde{B}_i(t-1, \vec{v})$ at time $t-1$.
- Motion Compensation: A residue block $R_i(t) \equiv B_i(t) - \tilde{B}_i(t-1, \vec{v})$.
- Coding: Quantized DCT coefficients $Q(DCT(R_i(t)))$ are transmitted with motion vector \vec{v} .

In high-quality video compression applications, e.g., video broadcasting, quantization scales are usually low. Consequently, the number of bits for residues dominates the total number of bits. In this context, it has been believed (until around 1996) that a smaller residue would yield fewer the bits for each block and thus the total bit rate would be smaller. Hence, the minimal-residue criterion is still widely used in BMAs as:

$$motion\ vector = \arg\min_{\vec{v}} \{SAD(\vec{v})\} \quad (1)$$

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 Namely, the motion vector for this block is the displacement vector that carries the minimal SAD (sum of the absolute difference).

Among many motion-estimation algorithms that have been proposed,^{5,6} the best solution in terms of a minimized estimation error is given by the full-search method. It is well-known that the amount of computation that is needed for this search is large, hence a great deal of effort has been spent to find faster algorithms that do not reduce the quality by too much. Besides computation, one other drawback of minimum-residue BMAs is that they usually do not produce the true motion field. As a result, the subjective quality of the decoded image sequence may be compromised since the motion estimation has chosen a set of motion vectors that give minimum-residue but fail to track the true motion. Additionally, minimum-residue BMAs cannot produce the optimal bit rate for very low bit rate video coding. Since the motion vectors are differentially encoded, it is not always true that a smaller residue will result in a reduced bit rate. The reason is that the total number of bits also includes the number of bits for coding motion vectors. Consequently, conventional BMAs that treat the motion estimation problem as an optimization problem on residue only could suffer the high price of differentially coding motion vectors.^{7,8}

Because a piecewise continuous motion field is attractive in reducing the bit rate for differentially encoded motion vectors, we present a motion tracker based on neighborhood relaxation. This approach offers rate-optimized motion estimation and is expressed as:¹

$$\text{motion of } B_i = \arg \min_{\vec{v}} \{ \text{SAD}(B_i, \vec{v}) + \sum_{B_j \in \mathcal{N}(B_i)} \mu_{i,j} \times \text{SAD}(B_j, \vec{v} + \vec{\delta}) \} \quad (2)$$

where a small $\vec{\delta}$ is incorporated to allow local variations of motion vectors among neighboring blocks, which comes from the non-translational motions, and $\mu_{i,j}$ is the weighting factor for different neighboring blocks*. In our algorithm, the motion of a block is determined by consulting the direction of all its neighboring blocks. The proposed score function is the weighted sum of the residue of the block itself and the residues of its neighbors. On the contrary, the residue of the block itself is the score function in BMAs.

Since the pixels of the same moving object move in a consistent way, there should be a good degree of motion smoothness between the neighboring region. A current block is influenced by the direction of motion which all of its neighboring blocks are experiencing. This allows the chance that a singular and erroneous motion vector be corrected by its surrounding motion vectors. The same principles are applied in median filtering. Therefore, our algorithm can track the physical motion in the video better than the conventional minimal-residue BMA.³

We should note that the neighborhood influences are part of the optimization criteria, just like SNAKE.⁹ Moreover, the residue of the central block in the score function is called the image force and the residue of the neighboring blocks in the score function are called the constraint forces. These constraint forces reflect the influence of neighbors on the current block and smooth the estimated motion field. In turn, this will reduce the bit-rate for differentially coded motion vectors, but more importantly provide a more accurate tracking of the true motion.¹

3. POST-PROCESSING ERROR CONCEALMENT

A number of error concealment approaches have been developed to recover the damaged regions by adaptive interpolation in the spatial, temporal, and frequency domains. For a comprehensive review of these error concealment techniques, we refer the reader to a recent paper by Wang and Zhu.¹² In the spatial domain, one common theme has been to first extract local geometric information, e.g., edges, from a neighborhood of surrounding undamaged pixels, and then reconstruct each lost pixel by spatial interpolation.¹⁴⁻¹⁶ In the frequency domain, one approach is to estimate missing DCT coefficients so that the spatial and temporal variation of adjacent pixels in the block is minimized.¹³

In the temporal domain, error concealment techniques that replace the lost region with the corresponding region in the previous frame have been proposed. The simplest method is to copy the block location directly from the previous frame. Another is to replace the lost region with the affine transformation of the corresponding region in the previous frame.¹⁷ Still another is to have temporal error concealment with block motion compensation.^{18,19} Since the emphasis of this paper is on the motion estimation which is used to assist the error concealment, the remainder of this paper will only consider temporal domain approaches. In addition, for the time being, we assume that the damage to the bit-stream has only affected the current frame, and the previous frames are intact. In this way, our problem is localized and restricted. We attempt to recover a damaged frame from the previous frame with no damage.

* In practice, we use the 4 nearest neighbors with $\mu_{i,j} \in [0.05, 0.40]$.

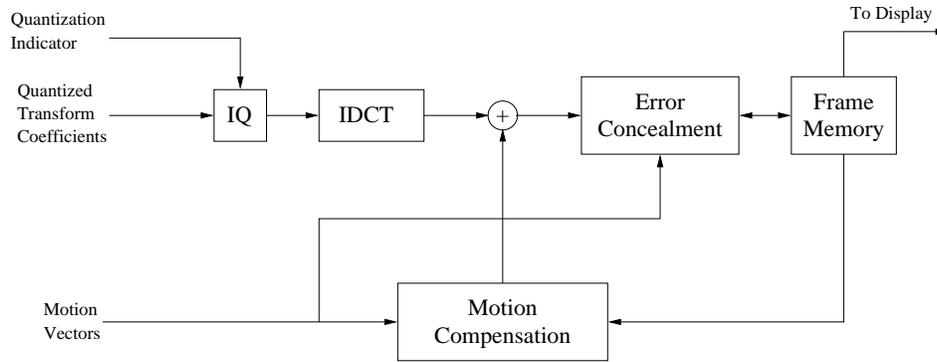


Figure 2. The post-processing error concealment scheme, which uses the decoded motion vectors. After a variable-length coding decoder (VLD), a basic MPEG decoder includes an inverse quantization (IQ), an inverse discrete cosine transform (IDCT), and a motion compensation (cf. Figure 1). The post-processing error concealment scheme uses the decoded motion vectors for motion-compensated interpolation.

Our scheme is classified as post-processing error concealment that uses motion-based temporal interpolation to recover damaged image regions. As shown in Figure 2, the motion information is extracted directly from the compressed bit-stream, and then fed as input to a post-processing mechanism. It is assumed that the damaged image regions are detected and a true motion estimation algorithm is used at the encoder. At the decoder, the true motion vectors are used to assist with the post-processing error concealment operation.

In this section, we present the three different error conditions that are considered in this paper and the corresponding error concealment techniques that are proposed. First, we consider the enhancement of existing error concealment schemes and discuss how our true motion estimation can achieve improved performance. Then, a novel idea regarding the extrapolation of motion vectors is proposed to improve the prediction of successive frames if the immediate reference frame has been heavily damaged. All of the proposed techniques assume that the true motion vector as described in the previous section is transmitted by the encoder.

3.1. Error Conditions

Case 1: Loss of motion vectors and residue

Usually, experiments with error concealment are considered in the context of a specified bit-error rate (BER) and/or a particular burst length. These errors usually occur during the transmission of a bit-stream and bit-streams are usually packetized prior to transmission.^{12,16} Therefore, unless there is some syntax in the bit-streams which supports the recovery of these error bits, it can be assumed that the loss will affect all of the information corresponding to a particular image data segment, which in the case of video coding is the macroblock. As a result, the first error case that we consider is one for which the motion vector and residual information for a number of blocks are lost.

Case 2: Loss of motion vectors only

Often, in the transmission of video sequences, an attempt will be made to protect the motion vectors better than the residual information. The reason is that the motion vector information provides significantly more information regarding the reconstructed block than the residual does. Since this is so, it is not very interesting from the perspective of motion estimation to study the effects of the residual loss, but rather examine the case of having the residual only and losing the motion. As a result, the second error case that we consider is to reconstruct the damaged block without its corresponding motion information.

Case 3: Previous frame is heavily damaged

The third error case that we consider is one that considers the case of predicting the next frame from a heavily damaged frame. Here, we argue that if true motion vectors are transmitted, it is better to make the prediction from the frame before the error. If this is done, it is crucial that the motion estimation is providing an accurate representation of the motion within the scene. Otherwise, the error due to inaccurate motion can cause worse problems than if the prediction were made from the damaged frame. When predictions are made from damaged blocks, the effects will be propagated until the end of the group of picture (GOP).

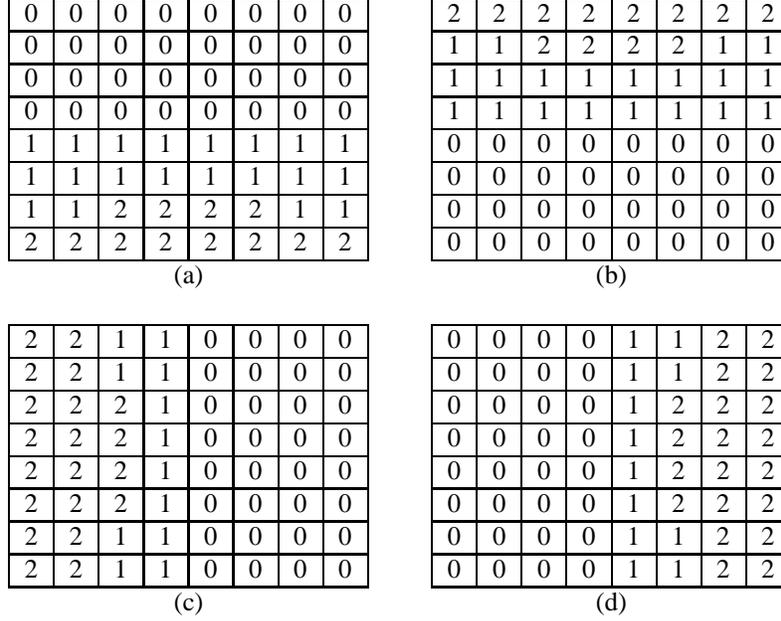


Figure 3. Weighting coefficients in the overlapped block motion compensation (OBMC) scheme when the block size is 8×8 ^{10,11} and the motion vector of the current block is lost. (a) shows the influence from the block under the current block. (b)(c)(d) show the influence from the above/left/right. In this case, a pixel in B_i will be motion-compensated by two motion vectors—one is the motion vector of the vertical neighbor of B_i and one is the motion vector of the horizontal neighbor block of B_i . The *weighted* motion compensation scheme will (1) put more weights on the pixels that are closer to the source block center and, (2) put fewer weights on the pixels that are on the block boundary, and (3) put even no weights on the pixels that are too far away. This scheme smoothes out motion vector differences gradually from one block to the next block.

3.2. Error Concealment Using Motion Interpolation

First, we consider the first case and the second case where only a small portion of image information is lost. In this case, we can make use of neighbor information to interpolate the lost information. In order to show that the use of our true motion tracker (TMT) can improve the performance of error concealment techniques that rely on neighbor information, two different schemes are considered. The first approach can be derived from the same way as motion vectors are commonly predicted for coding purposes.¹⁰ This method essentially recovers the motion vectors by applying a median filter to a neighborhood of blocks. This neighborhood usually consists of three previously decoded motion vectors.

The second approach has been proposed by Chen, Chen, and Weng.¹⁹ This approach combines the overlapped block motion compensation (OBMC) and side match criteria to minimize block artifacts. While being similar to the previous approach that tries to predict the motion of the current block, this scheme does not use one single motion vector. This scheme predicts the motion-compensated results using weighted average of the motion vectors from neighboring blocks. Figure 3 shows the weighting coefficients when the block size is 8×8 . In this case, a pixel in B_i will be motion-compensated by two motion vectors—one is the motion vector of the vertical neighbor of B_i and one is the motion vector of the horizontal neighbor block of B_i . This OBMC scheme will put weights based on the distance to the center of the weighting source. Because this scheme smoothes out motion vector differences gradually from one block to the next block, this scheme gives better subjective picture quality than many other methods.

Although each method has its uniqueness, they both rely on the motion vectors that are transmitted. We claim that our method of true motion estimation can be applied to each of these schemes, where significant gains in the error concealment can be realized. In the context of the error conditions discussed above, this means that we are only attempting to recover the motion information. For the first error condition in which the residue is also lost, no attempt is made to compensate for this loss. As a result, the concealed images under the first and second error conditions will be the same except that the second has the residue. This will be informative so that we can see the impact of the residue on the perceived recovery.

3.3. Error Concealment Using Motion Extrapolation

In Section 3.2, we have only discussed the case in which one frame has been damaged and we wish to recover damaged blocks using information that is already contained in the bit-stream. The temporal domain techniques that we have considered rely on information in the previous frame to perform the reconstruction. However, if the previous frame is heavily damaged, the prediction of the next frame may also be affected. For this reason, we must consider making the prediction before the errors have occurred. Obviously, if one frame has been heavily damaged, but the frame before that has not been damaged, it makes sense to investigate how the motion vectors can be extrapolated to obtain a reasonable prediction from a past reference frame.

Following this notion, we have essentially divided the problem of error concealment into two parts. The first part assumes that the previous frames are intact or are close to intact. This will always be the case for low BER and short error bursts. Furthermore, a localized solution such as the techniques presented in the previous subsection will usually perform well. However, if the BER is high and/or the burst length is long, the impact of a damaged frame can propagate, hence the problem is more global and seems to require a more advanced solution, i.e., one which considers the impact over multiple frames. In the following, we propose an approach that considers making predictions from a past reference frame, which has not been damaged.

More specifically, if there are errors in many blocks of frame $F(t)$, it may be better to use the blocks in frame $F(t-1)$ as a reference in performing the motion compensation for frame $F(t+1)$. In an error-free condition, $F(t+1)$ depends on $F(t)$ through a set of motion vectors, \vec{v} . However, when there are some regions in $F(t)$ that are damaged, we should modify the motion information that we are given to correspond with frame $F(t-1)$. This relation may not be so straightforward, but if we assume that motion field is piecewise continuous in the temporal domain, we can approximate a motion vector by extrapolating the motion vectors from different frames. In other words, if the decoded motion vector from $F(t)$ to $F(t+1)$ for a particular block is (v_x, v_y) , the motion vector from $F(t-1)$ to $F(t+1)$ should be approximately $(2v_x, 2v_y)$.

4. SIMULATION RESULTS

The focus of the simulation results shown in this section is to demonstrate that improved error concealment is achieved by making use of a better motion estimation algorithm at the encoder. It should be emphasized that a new error concealment technique is not proposed for single frame errors, but rather we highlight the significance of the information that is used in various recovery schemes. For heavily damaged frames, a new idea has been proposed to alter the transmitted motion vectors that point to damaged frames and make predictions from the previous reference frame.

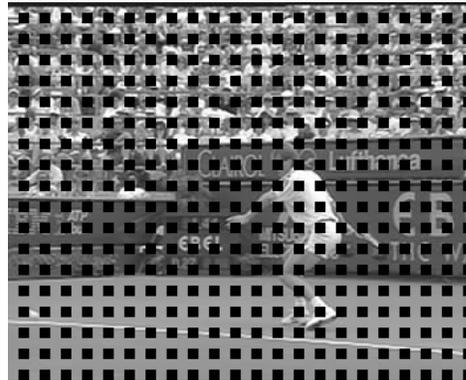
In the first set of experiments, we simulate the first error condition in which both the motion and residue information is lost (cf. Section 3.1). The three methods which were discussed in the previous section are used to recover the missing blocks at the decoder: (1) copy the block directly from the previous frame in the same location, (2) motion compensate with the motion vector predicted from a media filter, and (3) replace the lost block using the OBMC scheme. With these experiments, we can examine the impact of losing the motion vector and residue for different recovery techniques and different motion estimation algorithms. Table 1 provides the numerical results of the simulations under these error conditions. It is evident from this table that the OBMC approach performs better than the median filter approach, and the median filter approach performs better than the repeat last approach. We see that for the most part within each approach, our true motion tracker (TMT) performs better than BMA, except for the akiyo and mother_daughter sequences. These sequences are slow moving; hence the motion information is less significant than the residue information.

In the second set of experiments, we simulate the second error condition, which suffers from a loss of motion information only. The three methods, which were discussed in the previous section are used to recover the missing blocks at the decoder: repeat last, median filter, and OBMC. For each of these methods, one set of results uses minimum-residue BMA, and the other uses our true motion estimation algorithm. The numerical results are given in Table 2. It is evident from this table that the OBMC approach performs better than the median filter approach, and the median filter approach performs better than the repeat last approach. More importantly, within each approach, moderate gains on the order of 1dB are achieved when using the TMT.

Visually, the differences between different error concealment techniques can be seen in Figure 4. In Figure 4(a), the original image is shown, and in Figure 4(b), the blocks which are affected by the loss in motion are blacked out. It is obvious that the results generated with the TMT, (d) and (f), provide significant visual improvement over the results generated using a standard BMA algorithm, (c) and (e). These findings not only allow us to conclude that the TMT offers advantages over minimum-residue BMA, but allows us to conclude that the TMT offers advantages over minimum-residue BMA for a certain class of error concealment techniques, namely temporal domain approaches.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 4. Comparison of *different recovery methods* using *different motion estimation algorithms* in the stefan sequence. All errors are generated by loss of motion only. (a) original frame 98, (b) error image, blocks which have been blacked out are affected, (c) recovered frame using BMA and median filter, (d) recovered using TMT and median filter, (e) recovered using BMA and OBMC method, (f) recovered using TMT and OBMC method.

| Video sequence | Repeat last blocks | Use \vec{v} by median filter | | Use weighted average | |
|-----------------|--------------------|--------------------------------|-------|----------------------|-------|
| | | BMA | TMT | BMA | TMT |
| akiyo | 38.82 | 40.80 | 40.46 | 42.07 | 41.71 |
| coastguard | 23.91 | 28.15 | 28.49 | 29.69 | 29.81 |
| container | 37.70 | 37.83 | 37.97 | 38.15 | 38.26 |
| foreman | 23.71 | 27.21 | 27.78 | 29.66 | 29.79 |
| hall monitor | 33.06 | 33.33 | 33.59 | 34.74 | 34.83 |
| mother daughter | 35.86 | 37.84 | 37.74 | 39.23 | 38.91 |
| news | 30.22 | 31.37 | 32.16 | 33.95 | 34.44 |
| stefan | 17.14 | 19.67 | 20.18 | 21.85 | 22.34 |
| Average | 30.05 | 32.03 | 32.30 | 33.67 | 33.76 |

Table 1. Comparison of different error concealment techniques with two motion estimation algorithms when a small portion of motion vectors and residue information are lost.

| Video sequence | Repeat blocks in last frame | | Use \vec{v} by median filter | | Use weighted average | |
|-----------------|-----------------------------|-------|--------------------------------|-------|----------------------|-------|
| | BMA | TMT | BMA | TMT | BMA | TMT |
| akiyo | 40.27 | 40.78 | 43.33 | 43.52 | 45.25 | 45.58 |
| coastguard | 24.38 | 24.58 | 29.53 | 30.64 | 31.42 | 32.55 |
| container | 45.48 | 45.74 | 46.32 | 47.60 | 48.50 | 50.02 |
| foreman | 24.25 | 24.41 | 28.45 | 29.67 | 31.20 | 32.09 |
| hall monitor | 35.43 | 36.06 | 35.72 | 36.89 | 37.56 | 38.69 |
| mother daughter | 37.46 | 38.03 | 40.39 | 41.28 | 42.15 | 43.02 |
| news | 31.12 | 31.40 | 32.46 | 33.91 | 35.20 | 36.49 |
| stefan | 17.62 | 17.68 | 20.49 | 21.30 | 22.77 | 23.69 |
| Average | 32.00 | 32.34 | 34.59 | 35.60 | 36.76 | 37.77 |

Table 2. Comparison of different error concealment techniques with two motion estimation algorithms when motion vectors are lost.

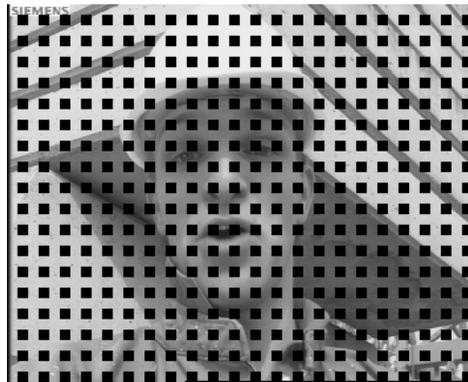
In Figures 5(c) and (d), some visual differences can be observed in the recovered frames of the foreman sequence when a small portion of the motion vector and the residual information are lost. In the TMT assisted results, the brim of the hat is less blocky, and also the teeth are better defined. Additionally, for comparison purposes, the results with motion loss only are shown in Figures 5(e) and (f). It can be observed that the results are similar to the results with motion and residue loss. To avoid objectivity, all these results were generated using the same OBMC recovery method. This allows us to conclude that, in general, TMT outperforms BMA, and the loss of the residue does not have a significant impact on recovered quality.

For the last set of experiments, we test the feasibility of our idea to improve error concealment by altering received motion vectors and making predictions from the previous reference frame. We should note that this idea is still at a preliminary stage since the assumption of piecewise linear motion over a larger time interval may not always be appropriate. The results are presented in Table 3. This table shows the comparison of results when the next frame is predicted from a damaged frame and when the next frame is predicted from the previous reference frame. In the case that the prediction is made from the previous reference frame, both TMT and BMA are simulated.

To clarify, a heavily damaged frame is one in which neighboring blocks are damaged as well. In that case, any temporal domain recovery approach would not have access to motion information from adjacent blocks and the error concealment technique replaces the lost region with the corresponding region in the previous frame. We observe that the SNRs of the prediction from the damaged frame correspond to those SNRs of repeating the blocks from the last frame in Tables 2 and 1. Overall, we see that the idea of predicting from the previous reference frame can be extremely beneficial. However, only moderate gains are achieved by the TMT over the BMA.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 5. Comparison of *same recovery method* using *different motion estimation* algorithms in the foreman sequence. All methods use OBMC recovery. (a) original frame 82, (b) error image, blocks which have been blacked out are damaged, (c) loss of motion and residue, use BMA, (d) loss of motion and residue, use TMT, (e) loss of motion, use BMA, (f) loss of motion, use TMT.

| Sequence | Refer to last frame | Skip last frame | |
|-----------------|---------------------|-----------------|-------|
| | | BMA | TMT |
| akiyo | 38.82 | 41.12 | 41.03 |
| coastguard | 23.91 | 28.48 | 28.48 |
| container | 37.70 | 37.98 | 38.12 |
| foreman | 23.71 | 26.38 | 26.86 |
| hall monitor | 33.06 | 34.62 | 34.82 |
| mother daughter | 35.86 | 37.64 | 37.69 |
| news | 30.22 | 29.97 | 30.58 |
| stefan | 17.14 | 19.90 | 20.20 |
| Average | 30.05 | 32.01 | 32.22 |

Table 3. Comparison of different error concealment techniques with two motion estimation algorithms when the last frame is heavily damaged.

5. CONCLUSIONS

This paper has examined the effects of motion estimation on a class of error concealment schemes that rely on motion vector recovery, where the recovery is not obtained through the support of any syntax. In the context of these schemes, we have demonstrated that our true motion tracker (TMT) provides significant advantages over minimum-residue BMAs. The reason is that the motion vectors we find more accurately represents the real world movement. The trade-off between the number of bits used for motion and texture is also considered. This encourages the motion field to be more fluent; hence, greater correlations exist among the motion vectors. This motion estimation algorithm has been implemented on two specific schemes—the median filter and OBMC-type schemes—and has shown improvement in both.

While the previous experiments have not introduced a new error concealment technique, we have shown that motion estimation has significant impact on the error concealment of a damaged frame. With this, we also investigate the impact of making predictions from a heavily damaged frame. It has been observed that in the case of a heavily damaged frame, better predictions can be made from the past reference frame, rather than the current reference frame which is damaged. This is accomplished by extrapolating the decoded motion vectors so that they correspond to the past reference frame.

Currently, a very simple scheme is employed for the extrapolation of motion vectors. That is, the motion vectors are doubled for every block. Although this is consistent with the assumption of piecewise linear motion between frames, this assumption may not hold over a larger time interval. As the next step, we plan to investigate how region-based global motion parameters can assist in determining a function that will allow us to more accurately extrapolate the motion vectors so that they better correspond to the past reference frame. Additionally, there must be a mechanism that automatically detects when the extrapolation scheme is best employed. This would lead way for an adaptive scheme as well.

REFERENCES

1. Y.-K. Chen and S.-Y. Kung. Rate Optimization by True Motion Estimation. In *Proc. of IEEE Workshop on Multimedia Signal Processing*, pages 187–194, Princeton, NJ, June 1997.
2. Y.-K. Chen, A. Vetro, H. Sun, and S.-Y. Kung. Frame Rate Up-Conversion Using Transmitted True Motion. to appear in *Proc. of 1998 Workshop on Multimedia Signal Processing*, December 1998.
3. Y.-K. Chen, Y.-T. Lin, and S.-Y. Kung. A Feature Tracking Algorithm Using Neighborhood Relaxation with Multi-Candidate Pre-Screening. In *Proc. of IEEE Int'l Conf. on Image Processing*, volume II, pages 513–516, Lausanne, Switzerland, September 1996.
4. D. Le Gall. MPEG: A Video Compression Standard for Multimedia Applications. *Communications of the ACM*, 34(4), April 1991.
5. J. Chalidabhongse and C.-C. Jay Kuo. Fast Motion Vector Estimation Using Multiresolution-Spatio-Temporal Correlations. *IEEE Trans. on Circuits and Systems for Video Technology*, 7(3):477–488, June 1997.
6. F. Dufaux and F. Moscheni. Motion Estimation Techniques for Digital TV: A Review and a New Contribution. *Proceedings of the IEEE*, 83(6):858–876, June 1995.
7. F. Chen, J. D. Villasenor, and D.-S. Park. A Low-Complexity Rate-Distortion Model for Motion Estimation in H.263. In *Proc. of IEEE Int'l Conf. on Image Processing*, volume II, pages 517–520, September 1996.

8. M. C. Chen and A. N. Willson, Jr. Rate-Distortion Optimal Motion Estimation Algorithm for Video Coding. In *Proc. of IEEE Int'l Conf. on Acoustics, Speech, and Signal Processing*, volume IV, pages 2098–2111, May 1996.
9. M. Kass, A. Witkin, and D. Terzopoulos. Snakes: Active Contour Models. *International Journal of Computer Vision*, 1(4):321–331, 1988.
10. MPEG-4 Video Verification Model V.11. ISO/IEC JTC1/SC29/WG11 Coding of Moving Pictures and Associated Audio MPEG98/N2472, October 1998.
11. ITU Telecommunication Standardization Sector. ITU-T Recommendation H.263 Video Coding for Low Bitrate Communication. <ftp://ftp.std.com/vendors/PictureTel/h324/>, May 1996.
12. Y. Wang and Q. F. Zhu. Error Control and Concealment for Video Communications: A Review. *Proceedings of the IEEE*, vol. 86, num. 5, pgs. 974–997, May 1998.
13. Q. F. Zhu, Y. Wang, and L. Shaw. Coding and Cell-Loss Recovery in DCT-Based Packet Video. *IEEE Transactions on Circuits and Systems for Video Technology*, 3(3):248–258, June 1993.
14. P. Salama, N. B. Shroff, E. J. Coyle, and E. J. Delp. Error Concealment Techniques for Encoded Video Streams. In *Proc. of IEEE Int'l Conf. on Image Processing*, volume I, pages 9–12, 1995.
15. H. Sun and W. Kwok. Concealment of Damaged Block Transform Coded Images Using Projections onto Convex Sets. *IEEE Transactions on Image Processing*, 4(4):470–477, April 1995.
16. W. Kwok and H. Sun. Multi-Directional Interpolation for Spatial Error Concealment. *IEEE Transactions on Consumer Electronics*, 39(3): 455–460, August 1993.
17. A. Tsai and J. Wilder. MPEG Video Error Concealment for ATM Networks. In *Proceedings of the IEEE International Conference on Acoustics, Speech & Signal Processing*, volume II, pages 2002–2005, Atlanta, GA, May 1996.
18. S. Aign and K. Fazel. Temporal & Spatial Error Concealment Techniques for Hierarchical MPEG-2 Video Codec. In *Proc. of IEEE Int'l Conf. on Communications*, volume 3, pages 1778–1783, 1995.
19. M. J. Chen, L. G. Chen, and R. M. Weng. Error Concealment of Lost Motion Vectors with Overlapped Motion Compensation. *IEEE Transactions on Circuits and Systems for Video Technology*, 7(3):560–563, June 1997.