Hybrid Error Concealment Using Linear Interpolation

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ABSTRACT

In this paper a hybrid error concealment algorithm using linear interpolation is proposed. In the proposed hybrid algorithm, the selective motion field interpolation (SMFI) is employed to conceal the erroneous macroblock. The spatial and temporal boundary-matched errors are then used to check whether the SMFI conceals the erroneous macroblock properly. If the temporally recovered macroblock is reconstructed incorrectly, the spatial error concealment using linear interpolation is employed to conceal the damaged macroblock instead of SMFI.

It can achieve better performance subjectively as well as objectively over other error concealment techniques such as AMV, FBBM and MFI. Simulation was conducted on the H.263 codec and the experimental results reveal that the proposed algorithm significantly outperforms other concealment techniques.

Keywords: Hybrid error concealment, Selective motion field interpolation, Linear interpolation

1. INTRODUCTION

During image or video data transmission a bit error might cause the loss of single or multiple macroblocks in a coded image or video sequence because of the use of a compression algorithm in the coded sequence. The error propagation problem can be solved by error correcting codes (e.g., Reed Solomon codes), automatic retransmission request (ARQ) or error concealment technique [1]. Among them the error concealment is an effective technique since no overhead or redundancy is required. Error concealment can be performed in the temporal domain, spatial domain or frequency domain. The temporal error concealment attempts to use the data from the past frames to restore the lost data, while the spatial error concealment attempts to use the data in the present frame to restore the lost data.

To eliminate the effect of bit errors, many efficient error concealment algorithms have been proposed in recent years. The conventional temporal error concealment technique makes use of adjacent motion vectors of the erroneous macroblocks and the previously decoded frames to conceal the erroneous macroblock. The simplest and commonly used method is the Temporal Replacement (TR), which replaces the erroneous macroblock with its collocated macroblock in the previously decoded frame. Another scheme for reconstructing the motion vector of the erroneous macroblock attempts to employ a linear combination of motion vectors of surrounding macroblocks in the current or previous reference frames, such as using average of neighboring motion vectors (AMV), or using forward-backward block matching (FBBM) [2] or boundary matching [3]-[5] algorithm to search the best-matched macroblock in the previously decoded frames. Other algorithms employ the Lagrange or polynomial interpolation to recover the lost motion vectors from the neighboring motion vectors and reconstruct the erroneous macroblocks [6]-[7].

The previously mentioned temporal error concealment techniques usually use one estimated motion vector for the whole lost macroblock and then uses estimated displacement to conceal the erroneous macroblock. The disadvantage of such techniques is that incorrect estimation of the motion vector could lead to poor concealment of the whole macroblock. Al-Mualla et al. [8]-[9] suggested a technique referred to as Motion Field Interpolation (MFI) for temporal error concealment that estimates the motion vector of the erroneous macroblock using the motion vectors of the four neighboring macroblocks and then each pixel in the erroneous macroblock is concealed individually with bilinear interpolation of the neighboring motion vectors.

The conventional spatial error concealment technique usually uses the neighboring pixels of an erroneous macroblock to restore the lost data. There are some good approaches to recover the lost macroblock such as linear interpolation using corner or nearest pixels [10]-[11] and directional interpolation that preserves the edge [12]-[13]. Some papers use more complex approaches such as Markov random field (MRF) [14]-[15], orientation adaptive [16] or NURBS interpolation [17] to recover the lost pixels. In most image or video compression (e.g., JPEG, MPEG, H.263 and H.264 standards), the original pixel blocks in the spatial domain are transformed into the frequency do-
main by discrete cosine transform (DCT). Since the DCT coefficients have similar characteristics in the neighboring blocks, the DC and AC coefficients of a lost macroblock can be restored from DCT coefficients of its neighboring macroblocks in this transform domain. This is referred to as the frequency error concealment, and some error concealment algorithms based upon DCT have been proposed [18]-[20].

Since the spatial error concealment technique uses spatial interpolation, it could cause the blurring effect. The effect introduced becomes severe for damaged macroblocks with edges. On other hand, the temporal error concealment technique attempts to recover the motion vectors of erroneous macroblocks. The incorrect estimation of the motion vector, however, could lead to visible artifacts at the boundaries with its neighbors. The incorrect motion vector usually occurs for the video sequences with fast motion or scene change. To achieve a better visible quality, some hybrid error concealment schemes have been proposed [11], [21]-[23] which uses a combination of both techniques to conceal the erroneous macroblocks. In this paper, we present a hybrid error concealment that combines the advantages of each technique and can improve the quality of the corrupted video objectively as well as subjectively. In the proposed hybrid technique both spatial and temporal error concealments are based upon the linear interpolation that is reasonably simple and yet provide a level of quality comparable or better than existing techniques.

The paper is organized as follows. In Section 2, the linear interpolation using nearest pixels for spatial error concealment is briefly reviewed. Section 3 describes the linear interpolation based upon the selective Motion Field Interpolation (SMFI) for temporal error concealment. The performance of the SMFI is provided and compared with the Motion Field Interpolation (MFI) and other concealment techniques in both objective and subjective measures. The hybrid error concealment based upon spatial and temporal smoothness properties is presented in Section 4, and the experimental results of the hybrid technique are presented in Section 5. The simulation results reveal that the proposed algorithm outperforms other techniques. Section 6 gives conclusion.

2. SPATIAL ERROR CONCEALMENT

As described previously, there are many spatial error concealment techniques to reconstruct the erroneous macroblocks, and among them the linear interpolation using nearest pixels is the simplest method to restore the lost data. The linear interpolation employs nearest pixels from the four surrounding macroblocks to calculate the pixel value of the erroneous macroblock. The corresponding four nearest pixels are weighted according to the opposite distance and divided by the sum of the distances. The interpolated value of each pixel in the erroneous macroblock is calculated by

\[
\hat{g}(x, y) = \frac{1}{d_L + d_R + d_B + d_T}\left\{d_L.g_L(x, y) + d_R.g_R(x, y) + d_B.g_B(x, y) + d_T.g_T(x, y)\right\}
\]  

That \(d_l\) represents the distance between \(g_l(x, y)\) and the neighboring pixel \(g_l(x, y)\). Although there exists many other advanced error concealment techniques, most of them are complicated and hard to implement in real-time processing. The linear interpolation is chosen in spatial error concealment for the hybrid technique due to its simplicity, and most importantly it can be implemented together with the selective motion field interpolation for temporal error concealment. If a nearest pixel is not available, it is assumed as 0; and for slice errors only pixels of both top and bottom neighboring macroblocks are considered.

3. SELECTIVE MOTION FIELD INTERPOLATION

Temporal error concealment techniques attempt to recover the lost data by exploiting the temporal redundancy of the video data. Motion vectors are estimated for the erroneous macroblocks and previously decoded frames are utilized to compensate for the erroneous macroblocks with the estimated motion vectors. This can be expressed as follows:

\[
\hat{G}_{l}(x, y) = G_r(x + d_x, y + d_y)
\]  

Where \(G_r\) is a macroblock in the previous reference frame used to conceal the erroneous macroblock \(G_l\), and \((d_x, d_y)\) is the estimated motion vector between \(G_l\) and \(G_r\). The simplest method is the temporal replacement (TR) that the estimated motion vector \(d = (d_x, d_y)\) is considered as a zero vector with assumption of no motion occurred between the current frame and the previous reference frame. More advanced techniques attempt to employ block matching or boundary-matching algorithm to search the best-matched macroblock from the previous decoded frames. All these techniques usually employ only one estimated motion vector to conceal the whole erroneous macroblock, and the main problem with such schemes is that incorrect estimation of the motion vector might cause obvious artifacts and lead to a poor concealment of the erroneous macroblock.

A. Motion Field Interpolation (MFI)

Al-Mualla et al. [8]-[9] suggested employing the Motion Field Interpolation (MFI) to provide a smoother motion field that reduces blocking artifacts. In the bilinear MFI the estimated motion vector \(d = (d_x, d_y)\) for each pixel \(g(x, y)\) within the lost macroblock is given by interpolating the neighboring motion vectors.
and rapid scene changes.

roblocks, especially for the area with slanting edges

iments show that most of macroblocks do not have a

result in a high degradation of visual quality. Exper-

ation vector

for pixel displacement estimation due to the fact that

motion vector will be estimated incorrectly using MFI

is contaminated with errors and lost. Then the lost

fast motion area (A area) with large motion vectors,

be expressed as

\[ d(x, y) = \frac{1}{d_T + d_R} (d_B) \]

where \( V_T, V_B, V_L \) and \( V_R \) respectively represent the

neighboring motion vectors of macroblocks to the

above, below, left and right to the lost macroblock;

\( d_T, d_B, d_L \) and \( d_R \) are the associated distances between

\( g(x, y) \) and the boundary. After normalization (i.e.,

with \( d_T + d_B = 1 \) and \( d_L + d_R = 1 \), \( d = (d_x, d_y) \) can

be expressed as

\[ d(x, y) = \frac{1}{2} (d_B \cdot V_T + d_R \cdot V_B +

\]

\[ d_L \cdot V_R + d_R \cdot V_L) \]

Once the motion vector is estimated, the lost pixel is

then concealed by

\[ \hat{g}(x, y) = g_r (x + d_x (x, y), y + d_y (x, y)) \]

The main advantage of MFI over the conventional

concealment (i.e., the whole erroneous macroblock is

concealed with only one estimated motion vector) is

that block artifacts can be alleviated due to each pixel

concealed individually. The problem with the MFI

technique, however, is that all the four neighboring

motion vectors for estimation might not be highly

correlated with the lost motion vector and it cannot

produce satisfactory results in areas with fast moving

or sudden scene change. This is illustrated in Fig. 1

that shows the motion vector of each macroblock in

two consecutive frames of the mobile video sequence.

As shown in Fig 1, consider that the macroblock with

motion vector \( d = (0, 1) \) in the area B, next to a

fast motion area (A area) with large motion vectors,

is contaminated with errors and lost. Then the lost

motion vector will be estimated incorrectly using MFI

that employs all the four neighboring motion vectors

for pixel displacement estimation due to the fact that

the motion vector of the top macroblock (with motion

vector \( d = (49, 0) \)) has a high dissimilarity with the

erroneous macroblock. This causes artifacts and

results in a high degradation of visual quality. Exper-

iments show that most of macroblocks do not have a

similar motion vector with all its neighboring macro-

blocks, especially for the area with slanting edges

and rapid scene changes.

B. Similarity between macroblocks

To improve the performance of the MFI, in this

work a selective MFI is proposed in which among

the four neighboring motion vectors only two highly

correlated motion vectors are selected to conceal the

pixel of the erroneous macroblock using linear inter-

polation. The two motion vectors chosen for error

concealment are based upon the difference or similarity

of the neighboring motion vectors in both current

and previous decoded frames. To describe the cor-

relation between the macroblocks or motion vectors,

we define the similarity on any two macroblocks as

\( S = \| V_i - V_j \| = | x_i - x_j | + | y_i - y_j | \), that \( V_i = (x_i, y_i) \)

and \( V_j = (x_j, y_j) \) are two motion vectors respectively.

When \( S \leq 2 \), the two macroblocks or motion vectors

are considered to be highly correlated or have high

similarity. Otherwise, they are not similar or not cor-

related to each other.

The experiment on similarity was conducted on several

video sequences of QCIF resolution (176x144

pixels). The H.263 codec was used to encode the

video sequences. The results for some video sequences

(foreman, carphone and claire), covering a wide range

of motion contents, are tabulated in Table I. For fore-

man sequence, the average percentages of high sim-

ilarity for these cases are 51.4%, 43.1% and 28.1%

respectively, and the result reveals that most mac-

roblocks have a higher similarity with 2 MBs on mo-

tion vectors than the other two. And a similar result

can be obtained for the other two sequences.

C. Selective Motion Field Interpolation (SMFI)

Since the experimental result indicates that a lin-

ear MFI might achieve a better motion vector recov-

ery than the conventional (bilinear) MFI, this work

investigates a selective MFI (SMFI) for temporal er-

ror concealment in which only two neighboring mo-

tion vectors with highest similarity are selected and

used in the estimation of the lost motion vector.

The selection is based upon the similarity between

neighboring motion vectors in the previous decoded

frame and current frame. There are nine neighbor-

ing motion vectors around the erroneous macroblock:

\( (V_C^{-1}, V_L^{-1}, V_R^{-1}, V_T^{-1}, V_B^{-1}) \) in the previous frame

and \( (V_C^i, V_L^i, V_R^i, V_T^i, V_B^i) \) in the current frame, as de-

picted in Fig. 2. The temporal similarity between the

central motion vector and it neighbors in the previous

frame \( i - 1 \) is given as

\[ S_{L}^{i-1} \equiv \| V_C^{i-1} - V_L^{i-1} \| \quad S_{T}^{i-1} \equiv \| V_C^{i-1} - V_T^{i-1} \|

\]

\[ S_{R}^{i-1} \equiv \| V_C^{i-1} - V_R^{i-1} \| \quad S_{B}^{i-1} \equiv \| V_C^{i-1} - V_B^{i-1} \| \]

The spatial similarity between the four neighboring

motion vectors in the current frame \( i \) is given as

\[ S_{LR}^i \equiv \| V_L^i - V_R^i \| \quad S_{LT}^i \equiv \| V_L^i - V_T^i \|

\]

\[ S_{LB}^i \equiv \| V_L^i - V_B^i \| \quad S_{RT}^i \equiv \| V_R^i - V_T^i \|

\]

\[ S_{RB}^i \equiv \| V_R^i - V_B^i \| \quad S_{TB}^i \equiv \| V_T^i - V_B^i \|

\]

The similarity between the erroneous macroblock

and its four neighbors are respectively defined as
In the selective MFI, the estimated motion vector \( d = (d_x, d_y) \) for each pixel \( g(x, y) \) within the erroneous macroblock is given by

\[
d(d_x(x, y), d_y(x, y)) = \frac{1}{2}(x + d_L.V_L + d_T.V_T + d_R.V_R)
\]

in which the two motion vectors that have highest similarity (i.e., smallest \( S \)) are selected for concealing each lost pixel of the erroneous macroblock, while the other two motion vectors with least similarity are assumed to be zeros. Each pixel \( \tilde{g}(x, y) \) within the erroneous macroblock is then concealed by

\[
\tilde{g}(x, y) = g_r(x + d_x(x, y), y + d_y(x, y))
\]

Note that if a neighboring motion vector is not available, it is assumed as 0; and if all three or four neighboring motion vectors are not available, the Temporal Replacement (TR) is employed for concealment instead.

### 4. HYBRID ERROR CONCEALMENT

As described previously, the spatial error concealment can hardly restore the details of the erroneous macroblock due to the blurring effect, while the temporal error concealment can completely reconstruct the erroneous macroblock if the motion vector is recovered correctly. The incorrect estimation of the motion vector, however, could lead to more severe degradation than the spatial error concealment. The incorrect estimation usually occurs in areas with fast/complex motion or sudden scene change.

Jo et al. [23] suggested a hybrid error concealment that adaptively combines the benefits of each error concealment technique. It makes use of the spatial smoothness property between adjacent pixels in the erroneous macroblock and its neighbors. The erroneous macroblock is firstly recovered using the temporal error concealment, then boundary-matching errors between the recovered macroblock and its neighbors are employed to determine whether the erroneous macroblock is concealed correctly or not. If the boundary-matching error is beyond a threshold, it means the temporal error concealment conceals the lost data improperly and the spatial error concealment is used to conceal the erroneous macroblock instead of the temporal error concealment.

The algorithm proposed in [23] was shown to outperform Sun’s hybrid algorithm [22]. It, however, only utilizes the spatial smoothness property to determine the accuracy of recovered motion vector for the erroneous macroblock. As a matter of fact, most video sequences possess spatial and temporal smoothness properties in the adjacent areas, and the accuracy of temporal error concealment can be determined more accurately by examining the boundary-matching errors between the temporally recovered macroblock and its neighbors from both current and previous reference frames.

In the proposed hybrid algorithm, we improve Jo’s algorithm by using both spatial and temporal boundary-matching errors to decide the accuracy of temporal error concealment. As depicted in Fig. 3, the spatial boundary-matching error between the temporally recovered macroblock \( G_{TR} \) and its neighbors \( G_{TC} \) and \( G_{BC} \), is given by

\[
BME_r = \frac{1}{2} \sum_{i=0}^{15} [g_r(x, 0) - g_{TC}(x, 0)]^2 + \frac{1}{2} \sum_{i=0}^{15} [g_r(x, 15) - g_{BC}(x, 16)]^2
\]

The index \( x \) and \( y \) of \( g_r(x, y) \), \( g_{TC}(x,y) \) and \( g_{BC}(x,y) \) represents the relative distance from the uppermost and leftmost pixel of \( G_{TR} \) and \( g_{R}(0,0) \) is the value of the uppermost and leftmost pixel. To check the spatial smoothness property, two average values of the boundary-matching errors between top macroblocks and between bottom macroblocks are respectively given as

\[
BME_t = \frac{1}{2} \sum_{y=1}^{16} [g_{TC}(0, y) - g_{TL}(-1, y)]^2 + \frac{1}{2} \sum_{y=1}^{16} [g_{TC}(15, y) - g_{TR}(16, y)]^2
\]

and

\[
BME_b = \frac{1}{2} \sum_{y=0}^{15} [g_{BC}(0, 16 + y) - g_{BL}(-1, 16 + y)]^2 + \frac{1}{2} \sum_{y=0}^{15} [g_{BC}(15, 16 + y) - g_{BR}(16, 16 + y)]^2
\]

The ratio of spatial boundary-matching errors \( \lambda_{SBME} \), defined as

\[
\lambda_{SBME} = \frac{2BME_r}{BME_t + BME_b}.
\]
5. EXPERIMENTAL RESULTS

is proposed in Jo’s algorithm [23], and it is employed to check whether the temporal error concealment conceals the erroneous macroblock properly. In addition to \( \lambda_{SBME} \), our proposed algorithm suggests another parameter, the ratio of temporal boundary-matching errors denoted as \( \lambda_{TBME} \), to determine the accuracy of temporal error concealment. The ratio of temporal boundary-matching errors \( \lambda_{TBME} \) is defined as

\[
\lambda_{TBME} = \frac{BME_t}{BME_{rl}},
\]

where

\[
BME_{rl} = \frac{1}{2} \sum_{x=0}^{15} [g_{RL}(x, 0) - g_{TCL}(x, -1)]^2 + \frac{1}{2} \sum_{x=0}^{15} [g_{RL}(x, 15) - g_{BCL}(x, 16)]^2
\]

indicates the boundary-matching error between its neighbors in the previous reference frame. Because of both spatial and temporal smoothness properties, \( \lambda_{SBME} \) and \( \lambda_{TBME} \) would be approximately equal to unity if the temporal error concealment conceals the damaged macroblock correctly. As both \( \lambda_{SBME} \) and \( \lambda_{TBME} \) exceed a threshold, it reveals that the SMFI conceals the damaged macroblock improperly, and the spatial error concealment is employed to reconstruct the erroneous macroblock. The proposed hybrid algorithm is summarized as follows:

Step 1: Find a lost macroblock.
Step 2: Use Selective Motion Field Interpolation (SMFI) to conceal the lost macroblock.
Step 3: Calculate \( BME_t, BME_s, BME_b \) and \( BME_{rl} \), and compute both \( \lambda_{SBME} \) and \( \lambda_{TBME} \).
Step 4: Compare \( \lambda_{SBME} \) and \( \lambda_{TBME} \) with threshold \( T_{SBME} \) and \( T_{TBME} \). If \( \lambda_{SBME} \geq T_{SBME} \) and \( \lambda_{TBME} \geq T_{TBME} \), go to Step 4.
Otherwise, go to Step 1.
Step 4: Use Linear interpolation with nearest pixels to reconstruct the lost macroblock.

5. EXPERIMENTAL RESULTS

The experiment was conducted on many video sequences to test and evaluate the performance of the hybrid error concealment algorithm. The selective motion field interpolation (SMFI) is first investigated and compared with motion field interpolation (MFI) as well as two widely used concealment techniques AMV and FBBM, which are shown to achieve better performance that the spatial error concealment technique except on the sequence with scene changes. The GOP structure is IPPPP..., i.e., all frames except the first frame are encoded as P frames, and the number of frames tested in a sequence is 101. The video sequences are contaminated with two types of errors (macroblock error and slice error respectively), starting from the fifth frame. A slice consisting of nine macroblocks is chosen to localize the errors, and if a slice error occurs resynchronization into the bit stream begins at the start of the next slice.

A. Experiments with Macroblock Error (ME)

Results for three QCIF sequences (foreman, carphone, and claire) and one CIF sequence (mobile) are given as follows. Table 2 displays the average PSNR performance over the first 101 frames, simulated on the foreman sequence that has relatively high motion activity with macroblock error rates (MER) 5%, 10% and 15% respectively. It is observed that the SMFI algorithm achieves a gain of approximately 2.5 dB on average over MFI and FBBM. The simulation result on the claire sequence that has low motion activity also reveals that the SMFI algorithm improves the FBBM and MFI by approximately 2 dB in average PSNR performance. A more detail PSNR performance in each frame simulated on foreman sequence is depicted in Fig. 4, in which each frame is contaminated with 10% MER, beginning with the fifth frames. As can be seen from the figure, the SMFI outperforms the other temporal error concealment techniques.

B. Experiments with Slice Error (SE)

The average PSNR over the first 101 frames simulated on several video sequences with various slice error rates (SER) was shown in Table 3, 4, 5, and 6 respectively. As shown, the MFI is able to achieve an average PSNR improvement of at least 1 dB over FBBM. Moreover, the SMFI averagely outperforms the MFI on all video sequences, and it has an average PSNR gain of 0.5 dB when the SER is 10%. Fig. 5 depicts the PSNR performance in each frame simulated on foreman sequence with 10% SER, which also shows the superiority of the SMFI. For subjective comparison, Fig. 6 demonstrates the concealed frame 50 of foreman sequence using the four different error concealment methods when the sequence was contaminated with 30% SER. As shown, the SMFI maintains a good visual quality as compared to other methods.

C. Performance of hybrid error concealment

Simulation results have demonstrated the superiority of the selective motion field interpolation (SMFI), and the SMFI is employed in the proposed hybrid error concealment algorithm for recovering the motion vector of the erroneous macroblock. The experiment was carried out on a MIX sequence that consists of foreman (20 frames), highway (40 frames) and mobile (40 frames) sequences, and has two scene changes respectively from the foreman sequence to the highway sequence, and from the highway sequence to the mobile sequence. The MIX sequence is contaminated with slice errors, starting from the fifth frame.

In the experiment, we assume \( \lambda_{SBME} = \lambda_{TBME} = \lambda_{SMFI} = \).
4 which gives good results. A comparison of PSNR performance is made in Fig. 7 with 20% SER that compares PSNR performance of the proposed hybrid algorithm and the one in [23]. Note that the hybrid algorithm in [23] employs the same spatial and temporal error concealment as that in our proposed algorithm (i.e., linear interpolation using nearest pixels and SMFI). The PSNR performance of using SMFI only is also displayed in the figure for comparison purpose. As shown, the proposed hybrid algorithm outperforms the algorithm in [23]. The hybrid algorithm in [23] can also detect the scene change correctly, and use spatial error concealment to conceal the erroneous macroblock instead of SMFI. As compared with the SMFI, however, it can be seen that the algorithm by [23] suffers from improperly concealing fast and complex motion areas in sequences that uses the spatial error concealment. And our proposed hybrid algorithm can significantly improve this degradation. Fig. 8 subjectively compares the decoded frame 16 of MIX sequence for both hybrid error concealments when the sequence was contaminated with 10% SER.

Table 7 shows the average PSNR performance for various slice errors. The simulation results show that the hybrid algorithm achieves average PSNR of 3 dB higher than that of using SMFI algorithm only. A subjective comparison is shown in Fig. 9 that demonstrates the damaged and the decoded frame 70 of the MIX sequence obtained by SMFI and our proposed hybrid algorithm.

6. CONCLUSION

This paper presented a hybrid error concealment algorithm using linear interpolation for error-prone video transmission channel. In the proposed hybrid algorithm, the temporal error concealment employing selective motion field interpolation (SMFI) is first used to conceal pixels in the erroneous macroblock. The spatial and temporal boundary-matched errors are then used to check whether the SMFI conceals the damaged macroblock correctly or not. If the temporally recovered macroblock is not concealed properly, the spatial error concealment using linear interpolation is employed instead of SMFI.

In the proposed SMFI, among the four neighboring motion vectors only two highly correlated motion vectors are selected to conceal each pixel of the erroneous macroblock using linear interpolation. Experimental results reveal that the proposed SMFI method achieves significant improvement on both PSNR performance and visual quality over other commonly used techniques. A gain of 2.5 dB on average over MFI and FBBM can be achieved with macroblock errors; and 0.5 dB and 1 dB over MFI and FBBM respectively with slice errors.

The proposed hybrid algorithm uses the linear interpolation on both spatial and temporal error concealment and it achieves better performance subjectively as well as objectively over other error concealment techniques.

References


Fig. 1: Movs (x, y) of two consecutive frames in MOBILE

Fig. 2: 2 Neighboring Motion Vectors around the Erroneous Macroblock

Fig. 3: Recovered Macroblock $G_R$ and its Neighbors
**Fig. 4:** PSNR Comparison of Different Methods for FOREMAN with 10% MER

**Fig. 5:** PSNR Comparison of Different Methods for FOREMAN with 10% SER

**Fig. 6:** Decoded frame 50 of FOREMAN sequence

**Fig. 7:** PSNR Comparison for FOREMAN Sequence with 20% SER

**Fig. 8:** Decoded Frame 16 of FOREMAN Sequence

**Fig. 9:** Decoded Frame 70 of MIX Sequence
### Table 1: Percentage of High Similarity

<table>
<thead>
<tr>
<th>Number of MB</th>
<th>PERCENTAGE OF HIGH SIMILARITY</th>
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<tbody>
<tr>
<td>2 MB</td>
<td>FOREMAN 51.4%</td>
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<tr>
<td>3 MB</td>
<td>CARPHONE 62.8%</td>
</tr>
<tr>
<td>4 MB</td>
<td>CLAIRE 55.9%</td>
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### Table 2: Average PSNR Performance Over 101 Frames of Foreman Sequence

<table>
<thead>
<tr>
<th>PSNR (Y) dB</th>
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<tr>
<td>MER Error free</td>
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<tr>
<td>5%</td>
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<tr>
<td>15%</td>
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</table>

### Table 3: Average PSNR Performance Over 101 Frames of Claïre Sequence

<table>
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<th>PSNR (Y) dB</th>
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<tbody>
<tr>
<td>SER Error free</td>
</tr>
<tr>
<td>10%</td>
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<tr>
<td>20%</td>
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<td>40%</td>
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### Table 4: Average PSNR Performance Over 101 Frames of Carphone Sequence

<table>
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<th>PSNR (Y) dB</th>
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<tr>
<td>SER Error free</td>
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<tr>
<td>10%</td>
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<tr>
<td>20%</td>
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<tr>
<td>30%</td>
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### Table 5: Average PSNR Performance Over 101 Frames of Mobile Sequence

<table>
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<th>PSNR (Y) dB</th>
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<td>SER Error free</td>
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<tr>
<td>5%</td>
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<tr>
<td>10%</td>
</tr>
<tr>
<td>20%</td>
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### Table 6: Average PSNR Performance Over 101 Frames of Mix Sequence

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<th>PSNR (Y) dB</th>
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<tr>
<td>SER Error free</td>
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<tr>
<td>5%</td>
</tr>
<tr>
<td>10%</td>
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<tr>
<td>15%</td>
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