Improved Side Information Generation Using Adaptive Overlapped Block Motion Compensation and Higher-Order Interpolation

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Abstract—This work addresses the twin issues of overlapping and blocking artifacts in Distributed Video Coding side information (SI). These both emanate from the block matching algorithm (BMA) used for motion vector (MV) generation rather than pixel-wise processing. In temporal correlation exploitation and particularly in the formulation of higher-order piecewise temporal trajectory interpolation (HOPTTI), BMA has been applied due to its speed and simplicity. While HOPTTTI has exhibited superior SI quality to other BMA-based algorithms, the adaptive overlapped block motion compensation (AOBMC) algorithm reduces the overlapping and blocky artifacts by adjusting the coefficients of a raised cosine overlapped window based on neighboring MV reliability. The aim of this paper is to investigate the benefits of combining HOPTTTI with AOBMC. A mode switching (MS) mechanism is introduced to exploit the spatial-temporal correlation in a sequence to select between frames which will benefit from combining HOPTTTI with AOBMC via a matching criterion. Experimental results confirm that selectively combining HOPTTTI with AOBMC gives better SI quality, with an average up to 1.8dB improvement compared to using only HOPTTTI, and up to 3.6dB improvement over existing AOBMC-based algorithms.

Keywords—wyner-ziv; side information; Higher order interpolation; distributed video coding; mode switching; adaptive overlapped block motion compensation.

I. INTRODUCTION

Distributed video coding (DVC) reverses the traditional coding paradigm of complex encoders allied with basic decoding, to one where the computational cost is incurred mainly by the decoder. DVC is a particular example of source coding that practically implements the Wyner-Ziv (WZ) [1] theorem pertaining to joint decoding of statistically correlated sources with side information (SI) available at the decoder using a lossy fidelity criterion. The exploitation of correlation at the decoder where original video frames are not available is non-trivial and one of the critical factors impacting upon DVC performance is SI quality [1–2].

Linear motion compensated temporal interpolation (LMCTI) has been widely adopted for SI generation, though recent findings [2, 3] show better peak signal to noise ratio (PSNR) can be achieved when a higher-order piecewise temporal trajectory interpolation (HOPTTTI) algorithm [2] is used to generate SI. Since object motion is not necessarily linear, HOPTTTI is able to better model these types of motion, using either 3 or more MVs from previous and future frames to predict the MV for a macroblock (MB) in the current frame.

Though HOPTTTI is able to more accurately model object motion, since a block matching algorithm (BMA) is used, it causes overlapping which lowers the PSNR wherever abrupt changes in trajectory and global motion occur. This is due to multiple overlapping trajectories created by MVs of previous and future frames when such motion occurs. Also, with blocking artifacts the PSNR is lowered when deformable objects are represented by a single MV for a MB which may contain differing motions.

The adaptive overlapped block-motion compensation (AOBMC) approach [4] allows the MV of a MB to be applied to larger groupings of pixels by using a raised cosine window, to more accurately model the aforementioned motions. Specifically, situations where a MB either contains multiple objects with varying motions or one object traverses multiple MBs, so it is represented by different MVs. The raised cosine window gives an enlarged window greater than the MB under consideration to allow the MV of the MB to be moderated by the MV of surrounding pixels in such a way that depends on the distance of the pixel from the aforementioned MB. This has led to AOBMC being employed in a number of variants to improve SI quality. In motion compensated frame interpolation and adaptive object block motion compensation (MCFI-AOBMC) [4] for instance, bilateral LMCTI is applied to overcome both hole and overlapping problems by coupling AOBMC with an object segmentation and MV clustering technique. In improved side information generation for distributed video coding (ISIG-DVC) [5], AOBMC is combined with a variable block-size refinement algorithm to produce improved SI, while the low complexity motion compensated frame interpolation (ALCFI) [6] also utilizes AOBMC this time together with MV smoothing. These AOBMC-based algorithms all attempt to some degree, to address the restrictions caused by BMA by using LMCTI in SI generation. This paper investigates applying the higher-order HOPTTTI algorithm alongside AOBMC to both enhance the SI quality and reduce BMA artifacts.
While an overall SI improvement is achieved, analysis reveals that for certain frames in various test sequences, HOPTTI produced better SI quality than when combined with AOBMC. The reason for this is that some of the neighboring MVs are not correlated with one another and their addition to the reference MB used in the enlarged window degrades the overall SI quality in that particular frame. A mode switching (MS) technique based on [7] is thus introduced which uses a matching criterion to switch between HOPTTI and AOBMC combined with HOPTTI (AOBMC-H) to obtain a Switched HOPTTI-AOBMC final SI. The corresponding impact on SI quality of both the new AOBMC-H approach and MS mechanism are analysed in this paper, with numerical and perceptual results exhibiting a consistent improvement in overall SI quality.

The remainder of this paper is organized as follows: Section II reviews both the HOPTTI and AOBMC algorithms and introduces the mode switching concept, while Section III presents a quantitative and qualitative results analysis of this SI generation scheme. Section IV provides some conclusions.

II. THE HOPTTI AND AOBMC ALGORITHMS AND MODE SELECTION (MS) MECHANISM

To deal with the issues relating to the use of BMA that introduces blocking artifacts and overlapping MVs, a higher order (cubic) trajectory model allied with adaptive overlapped compensation algorithm with a MS mechanism is used.

A. Higher Order Piecewise Temporal Trajectory Interpolation Formulation and Parameterization [2]

SI formulation for HOPTTI uses a higher order motion compensated temporal interpolation model that includes a variable acceleration (3rd order) paradigm. This allows the model to estimate the MVs of objects that exhibit sudden accelerated motion, such as a surge, popularly referred to as jolt [2]. The object motion trajectory is represented by a set of piecewise cubic polynomials as shown in 3-D space in Figure 1. A trajectory is estimated using parameters \(A_i, B_i, C_i\) and \(D_i\) which are the MVs of the corresponding MB in the previous and next frames. Forward and backward direction trajectories are then combined using bi-directional motion compensation, so the MV of the target MB is obtained.

B. Adaptive Overlapped Block Motion Compensation (AOBMC) Algorithm [4]

While higher-order interpolation with BMA for MV estimation has shown promising results [2–3], there are two issues to be resolved: i) MB overlapping caused by inaccurate MV estimations from the forward and backward trajectories; and ii) blocky artifacts caused by multiple or deformable objects having different motions in the same MB. These two scenarios are respectively illustrated in Figures 2 and 3. The former shows how multiple trajectories passing through the intermediate frame can cause overlapping, while Figure 3 presents the case where a four-pixel MB is traversed by only one trajectory, so the intermediate frame can only correctly locate pixel 1.

AOBMC is employed for each MB in the interpolated frame by applying its MV to a larger set of pixels using a raised cosine weighting window. The size of the window is determined by both the pixel distance from the block under consideration and the reliability of the neighboring MV. This is expressed by minimising the sum of boundary absolute difference (SBAD) [4]. SBAD is defined as:

![Figure 1. Example segments of the motion trajectory of an object in 3-D space between time \(t_1\) and \(t_\infty\), where \(K\) are the key frames and SI the side information of a WZ frame, \(T\) is the period between two key frames.](image1)

![Figure 2. Example of multiple motion trajectories of a block passing through the intermediate frame which leads to overlapping.](image2)

![Figure 3. Example of a 4-pixel block with each having different motions but being represented by one trajectory and MV.](image3)
The performance of the MS mechanism in improving SI quality will now be analysed.

III. EXPERIMENTAL RESULTS ANALYSIS

The HOPTTI algorithm was implemented in Matlab version 7.5.0 (R2007b) running under Microsoft Windows XP on a PC with an Intel Duo Core CPU at 2.20 GHz. A group-of-picture size of 2 was chosen for all experiments i.e. KKW, where K and W denote key and WZ frames respectively. HOPTTI [2] used a cubic trajectory and parameterization as outlined in Section II.A. To evaluate both quantitatively and qualitatively, HOPTTI with and without AOBMC, various QCIF (Quarter Common Intermediate Format) test sequences were applied including Carphone, Mother, Coastguard, Silent, Hall, Foreman and American Football, which provided a wide range of different types of motion and objects features. Both λ in (3) and the threshold T in the MS mechanism were determined empirically and set to λ = 0.4 and T = 10 which provided the best results.

Three other AOBMC-based implementations (see Section I) were used as SI quality performance comparators, namely MCFI-AOBMC [4], ISIG DVC [5] and ALCFI [6], with each being implemented using LMCTI. Table I shows the corresponding PSNR values for various test sequences, with the middle column showing the AOBMC-based variant. The results reveal that Switched HOPTTI-AOBMC consistently provided an SI improvement for each sequence analyzed, with Foreman for instance giving a 1.6dB PSNR improvement over both the original HOPTTI and various AOBMC-based results.

From a perceptual perspective, the sample frames from Hall and American Football shown in Figures 4 and 6 reveal how the inclusion of HOPTTI into the AOBMC algorithm and applying the MS mechanism qualitatively improved SI quality. These qualitative judgments are numerically confirmed in the average PSNR values in Table I, with improvements of 3.4dB and 1.4dB respectively over the other AOBMC variants. In Hall for example, the improvement is readily apparent in the extended leg of the moving object (man), while in American Football, perceptible object ghosting in the HOPTTI frame has been significantly attenuated in the Switched HOPTTI-AOBMC frame. The corresponding frame-wise plots corroborate the role of MS in ensuring that no frame for any sequence analysed had been significantly attenuated in the Switched HOPTTI-AOBMC frame.

IV. CONCLUSION

The paper tackles the twin problems of overlapping and blocking artifacts in higher order piecewise temporal trajectory interpolation (HOPTTI) due to the use of BMA by selectively incorporating it into the AOBMC algorithm, and using a mode switching mechanism to generate the Switched HOPTTI-AOBMC side information (SI). Both numerical and perceptual results confirm the SI quality improvement in applying the HOPTTI and AOBMC combination, with up to 3.6dB improvement in PSNR achieved.
TABLE I. AVERAGE PSNR (dB) FOR SWITCHED HOPTTI-AOBMC, HOPTTI and VARIOUS AOBMC ALGORITHMS FOR VARIOUS TEST SEQUENCES

<table>
<thead>
<tr>
<th>Sequences</th>
<th>Switched HOPTTI-AOBMC</th>
<th>AOBMC-related algorithms[^a]</th>
<th>HOPTTI [2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carphone</td>
<td>36.2</td>
<td>33.2 [6]</td>
<td>35.3</td>
</tr>
<tr>
<td>Mother</td>
<td>48.4</td>
<td>38.0 [6]</td>
<td>47.3</td>
</tr>
<tr>
<td>Foreman</td>
<td>36.7</td>
<td>36.0 [4]</td>
<td>35.1</td>
</tr>
<tr>
<td>Silent</td>
<td>39.9</td>
<td>-</td>
<td>38.9</td>
</tr>
<tr>
<td>Coastguard</td>
<td>37.9</td>
<td>34.08 [6]</td>
<td>36.4</td>
</tr>
<tr>
<td>Hall</td>
<td>39.9</td>
<td>36.5 [5]</td>
<td>38.5</td>
</tr>
</tbody>
</table>

[^a]: The best of [4], [5] or [6] have been included for each sequence in the table for the purposes of comparison.

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Figure 4. Sample frames for Hall showing the SI quality obtained using HOPTTI [2] and Switched HOPTTI-AOBMC.

Figure 5. Frame-wise SI-quality of Original HOPTTI [2] and Switched HOPTTI-AOBMC for Hall.

Figure 6. Frame-wise SI-quality of Original HOPTTI and Switched HOPTTI-AOBMC for the American Football sequence.

Figure 7. Sample frames for American Football showing the SI quality obtained using HOPTTI [2] and Switched HOPTTI-AOBMC.

REFERENCES


