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

Mobolaji O. Akinola[1], Laurence S. Dooley[2], Patrick K. C. Wong[3]
Department of Communication and Systems, *neXt Generation* Multimedia Technology (XGMT) Group, The Open University, Milton Keynes, MK7 6AA, United Kingdom
[1]m.o.akinola@open.ac.uk; [2]l.s.dooley@open.ac.uk; [3]k.c.p.wong@open.ac.uk

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 HOPTTI 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 HOPTTI 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 HOPTTI with AOBMC via a matching criterion. Experimental results confirm that selectively combining HOPTTI with AOBMC gives better SI quality, with on average up to 1.8dB improvement compared to using only HOPTII, 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 mation 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* (HOPTTI) algorithm [2] is used to generate SI. Since object motion is not necessarily linear, HOPTTI 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 HOPTTI 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 HOPTII 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, HOPTII 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_1, B_1, C_1 and D_1 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:

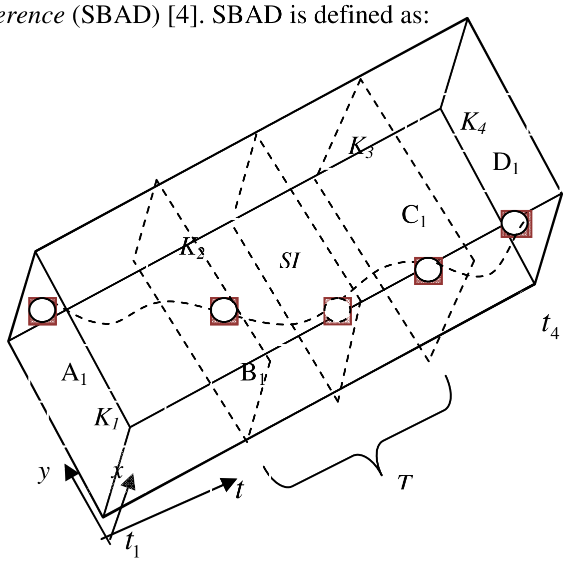

Figure 1. Example segments of the motion trajectory of an object in 3-D space between time t_1 and t_4, where K are the key frames and SI the side information of a WZ frame, T is the period between two key frames

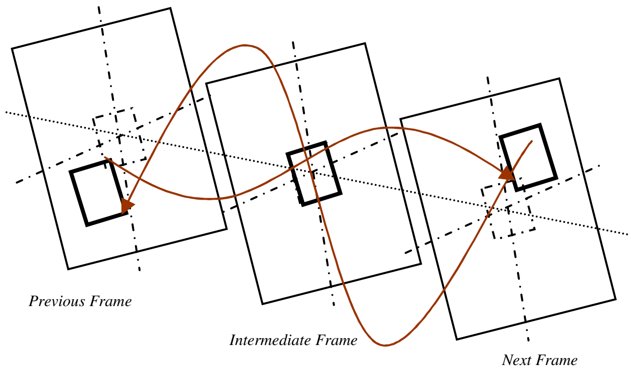

Figure 2. Example of multiple motion trajectories of a block passing through the intermediate frame which leads to overlapping.

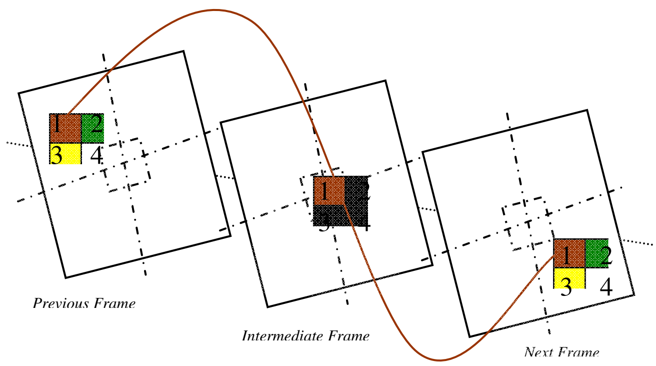

Figure 3. Example of a 4-pixel block with each having different motions but being represented by one trajectory and MV.

$$
\begin{aligned}
SBAD = & \frac{1}{M}\sum_{i=0}^{M-1} | F_1(i+x_0, y_0) - F_2(i+x_0+MV_x, y_0+MV_y-1) | \\
& + \frac{1}{M}\sum_{i=0}^{M-1} | F_1(i+x_0, y_0+N-1) - F_2(i+x_0+MV_x, y_0+MV_y+N) | \\
& + \frac{1}{N}\sum_{j=0}^{N-1} | F_1(x_0, j+y_0) - F_2(x_0+MV_x-1, j+y_0+MV_y) | \\
& + \frac{1}{N}\sum_{j=0}^{N-1} | F_1(x_0+M-1, j+y_0) - F_2(x_0+MV_x+M, j+y_0+MV_y) |
\end{aligned} \tag{1}
$$

Where (x_0, y_0) is the coordinate of the top left block of the interpolated frame F_1, F_2 is the HOPTTI SI frame used as the reference, since the original frame is not available at the decoder (MV_x, MV_y) is candidate MV and (M, N) are the dimensions of the block.

C. Mode Switching (MS) Algorithm

While AOBMC reduces errors caused by the scenarios discussed in Section II.B, the results produced by HOPTTI with AOBMC reveal that the aggregate sum of using the spatial correlation of pixels around a MB in AOBMC results in specific frames becoming degraded. The spatial-temporal pixel correlations surrounding a MB are exploited to determine those frames most likely to exhibit this tendency and this formed the basis of the MS facility.

The aim is to define a *matching criterion* (*M*) which determines the level of the spatial-temporal correlation and a threshold *T* that separates aggregate contributions to all the MBs in a frame. When *M* is less than *T*, it gives a negative aggregate contribution and as a consequence AOBMC-H is disabled, while the reverse holds when *M* is greater *T*, i.e., AOBMC-H is enabled. Therefore, in addition to the spatial measure SBAD that measures spatial continuity of MVs from the MB under investigation, the *sum of mean absolute difference* (SMAD) which measures temporal continuity is included in the matching criterion similar to [7]. SMAD is defined as:

$$
SMAD = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j}^{N-1} | F_1(i+x_0, j+y_0) - F_2(i+x_0+MV_x, j+y_0+MV_y) | \tag{2}
$$

where the various parameters are defined as in (1). A weighted sum of SMAD and SBAD is then used to form the matching criterion such that:

$$
M = \lambda * SBAD + (1-\lambda) * SMAD \tag{3}
$$

where λ is a predefined weighting factor. (3) exploits the spatial-temporal continuity of SBAD and SMAD as the measure to match the surrounding blocks with the reference MB. The MS mechanism applies a threshold *T* so:

Calculate *M* in (3)
If $M \leq T$ THEN apply HOPTTI with AOBMC
ELSE use HOPTII only
END

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. *KWKW*, 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 $\lambda = 0.4$ 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 the PSNR value for *Switched HOPTTI-AOBMC* lower than HOPTTI, i.e. HOPTTI provided a lower performance bound in terms of SI quality.

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 HOPTT-OABMC* 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*, HOPTII and VARIOUS AOBMC ALGORITHMS FOR VARIOUS TEST SEQUENCES

Sequences	***Switched HOPTTI-AOBMC***	***AOBMC-related algorithms [a] [4], [5] and [6]***	***HOPTTI [2]***
Carphone	36.2	33.2 [6]	35.3
Mother	48.4	38.0 [6]	47.3
Foreman	36.7	36.0 [4]	35.1
Silent	39.9	-	38.9
Coastguard	37.9	34.08 [6]	36.4
Hall	39.9	36.5 [5]	38.5
American Football	25.8	24.0 [4]	24.5

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

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

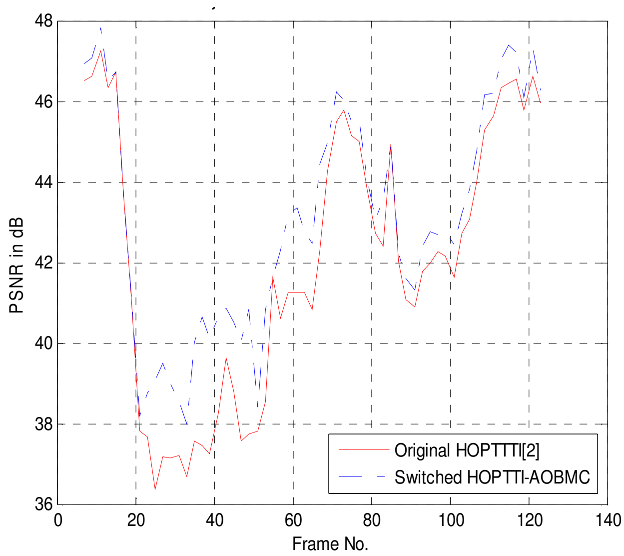

Figure 5. Frame-wise SI-quality of Original HOPTTI [2] and Switched HOPTTI-AOBMC for *Hall*

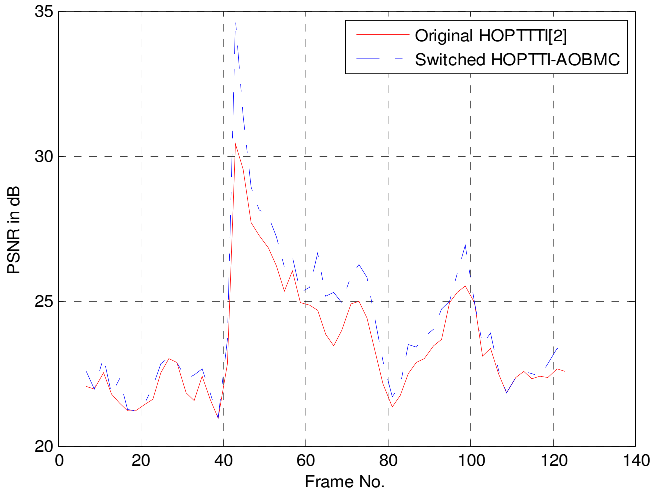

Figure 6. Frame-wise SI-quality of Original HOPTTI and *Switched HOPTTI-AOBMC* for the *American Football* sequence

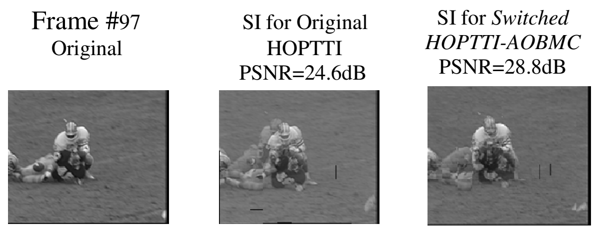

Figure 7. Sample frames for *American Football* showing the SI quality obtained using HOPTTI [2] and *Switched HOPTTI-AOBMC.*

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