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Motion Prediction and Motion Vector Cost Reduction during Fast Block Motion Estimation in MCTF

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***Abstract*—**In 3D-wavelet video coding framework temporal filtering is done along the trajectory of motion using Motion Compensated Temporal Filtering (MCTF). Hence computationally efficient motion estimation technique is the need of MCTF. In this paper a predictive technique is proposed in order to reduce the computational complexity of the MCTF framework, by exploiting the high correlation among the frames in a Group Of Picture (GOP). The proposed technique applies coarse and fine searches of any fast block based motion estimation, only to the first pair of frames in a GOP. The generated motion vectors are supplied to the next consecutive frames, even to subsequent temporal levels and only fine search is carried out around those predicted motion vectors. Hence coarse search is skipped for all the motion estimation in a GOP except for the first pair of frames. The technique has been tested for different fast block based motion estimation algorithms over different standard test sequences using MC-EZBC, a state-of-the-art scalable video coder. The simulation result reveals substantial reduction (i.e. 20.75% to 38.24%) in the number of search points during motion estimation, without compromising the quality of the reconstructed video compared to non-predictive techniques. Since the motion vectors of all the pair of frames in a GOP except the first pair will have value ±1 around the motion vectors of the previous pair of frames, the number of bits required for motion vectors is also reduced by 50%.

***Keywords*—**Motion Compensated Temporal Filtering, predictive motion estimation, lifted wavelet transform, motion vector

I. Introduction

Over the years, there has been an exponential growth in the users base and their demands in the multimedia domain. Video communication is an important component of multimedia applications, needing inherently higher bandwidth for transmission. This is achieved through video coding. The twin issues of the adaptation of single video bit-stream to varying transport conditions (bandwidth, error rate……), varying receiver capabilities (CPU, display size….) and insatiable demands of the users have been addressed through scalable video coding, where the compressed bit-streams are required to be scaled to requirement.

Scalability refers to a method that allows the partial decoding of a single compressed bitstream. Depending on the conditions (bit rate, errors…), the decoder can take a portion of the stream and decode the video sequence at different quality, spatial resolution and frame rates [1, 2].

The success of wavelet/subband coding has been shown in static image coding such as JPEG2000 [3]. The extension of this to motion picture coding relies on the efficient processing of motion compensation along the temporal dimension. Sizable amount of work has been done by many researchers for 3D-subband coding [4]. The MCTF applies filtering along the motion trajectory. This scheme has attracted many researchers due to its inherent property of supporting all types of scalability.

The lifting based implementation of the temporal filtering facilitates temporal filters longer than the Haar [18], subpixel accuracy for ME [16, 21, 6], bidirectional MC and multiple reference frames [16, 6, 22], multihypothesis MC [23, 24], ME/MC using meshes rather than blocks [24], and multiple-band schemes that increase temporal scalability [25].

MCTF can be used in two different stages in the video coding framework. In Spatial-Domain MCTF (SDMCTF) [15], spatial filtering follows temporal filtering and in In-Band MCTF (IBMCTF), temporal filtering follows spatial filtering. IBMCTF supports all types of scalability with high computational complexity. Recent research focuses on reducing the computational complexity of the scheme, by applying efficient techniques for wavelet domain motion estimation. The large amount of motion information generated needs to be coded, which is an active research area [7]. In this paper we propose a predictive technique for reducing the computational complexity of the motion estimation in MCTF framework. The number of bits required to represent the motion vectors are also reduced by 50%, except for the motion vectors of the first pair of frames in a GOP.

The rest of the paper is organized as follows. Section 2 explains Lifting-based MCTF. Section 3 covers block-based motion models. The details of the proposed technique are given in section 4. Results are discussed in section 5 and section 6 concludes the paper.

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II. Motion Compensated Temporal Filtering

The three primary objectives of motion adaptive temporal transform [5] are, (i) the low pass temporal subband frames should represent a high quality and reduced frame-rate video, (ii) the transform should exhibit high coding gain and (iii) the transform should be invertible.

Fig. 1 gives the temporal decomposition of a video sequence, I_0, $I_1 \ldots\ldots I_{2n+1}$ using bi-orthogonal 5/3 wavelet filter with lifting implementation.

The *prediction* is to calculate the high pass frame, which predicts the odd frame from consecutive even frames as follows,

$$H_i = I_{2i+1} - P(I_{2i+1})$$

where,

$$P(I_{2i+1}) = \frac{1}{2}(MC(I_{2i}, MV_{2i+1\to 2i}) + MC(I_{2i+2}, MV_{2i+1\to 2i+2}))$$

H_i is the high pass frame generated in the predict step, $MV_{2i+1\to 2i}$ and $MV_{2i+1\to 2i+2}$ are the motion vectors from the frame 2_{i+1} to 2_i and 2_{i+1} to 2_{i+2} respectively. MC() is the motion compensation process that generates the current frame's prediction from its consecutive frame.

The *update* step follows the predict step to complete one level 5/3 subband transform which generates the low pass frame.

$$L_i = I_{2i} + U(I_{2i})$$

where,

$$U(I_{2i}) = \frac{1}{4}(MC(H_{i-1}, MV_{2i\to 2i-1}) + MC(H_i, MV_{2i\to 2i+1}))$$

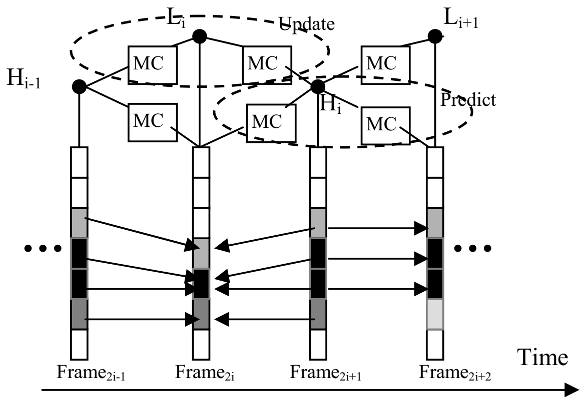

Fig. 1 One level lifting MCTF using bi-orthogonal 5/3 filters.

Block based motion model

The block based motion models are computationally efficient methods compared to their counter-part mesh based, object based and region-based models. In block-based models, the current frame is divided into blocks of equal size (8X8, 16X16…NXN). For each block in a current frame, a candidate block in the search window of the reference frame is found by motion estimation, using minimum Mean Square Error (MSE) (or mean absolute difference (MAD) or sum of absolute difference (SAD)) as a cost parameter.

$$MSE = \frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(C_{ij} - R_{ij})^2$$

Where C_{ij} and R_{ij} are the samples of current and reference block respectively of block size N X N.

The full search motion estimation gives global minimum but it is computationally very intensive. Hence various fast block-based motion estimation algorithms are proposed such as logarithmic search [8], three-step search (TSS), new three-step search (NTSS) [9], four step search (4SS) [10], block-based gradient decent search (BBGDS) [11], simple and efficient search (SES) [12], diamond search (DS) [13] and hexagon-based search (HEXBS) [14]. Almost all fast block estimation algorithms work in two stages, a low-resolution coarse search and following a fine-resolution inner search.

In Diamond Search (DS) [13], for all nine candidate positions shown in Fig. (2), in low-resolution MSE have to be found. The searching will continue until the center position itself gives the minimum MSE or search crosses the search window. Then search inner four positions as shown in Fig. (2) in fine-resolution, whichever position gives the minimum MSE that is the best match (or motion vector).

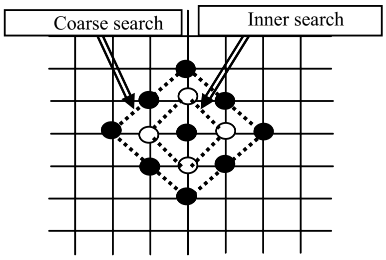

Fig. 2 Search pattern in Diamond Search.

In Hexagon Search (HEXBS) [14], for all seven positions in low-resolution as shown in Fig. (3) MSE has to be found, if center position gives the minimum MSE or crosses the search window, stop searching in low-resolution. Then search in the fine resolution, the minimum MSE position gives the final motion vector.

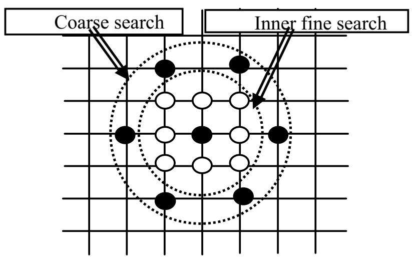

Fig. 3 Search pattern in Hexagon Search.

III. Proposed Technique

In any video due to its inherent nature, the frames along the temporal directions are highly correlated; the two stages (coarse and fine search) of any fast block motion estimation are not necessary for all the pairs of frames in a GOP.

This research work proposes a novel predictive technique for efficient implementation of fast block based motion technique during MCTF. In this the motion vectors between the first pair of frames in a GOP have to be found as usual with low-resolution coarse search and fine-resolution inner search as discussed in section II. While performing motion estimation between next consecutive frames and even in next temporal levels in a GOP, the previously available motion vectors are used as a result of coarse search. The predictive structure for MCTF used in this work is as shown in Fig. (4). The finer search will be performed around the predicted position (i.e. around the corresponding motion vector of the block in the previous frame).

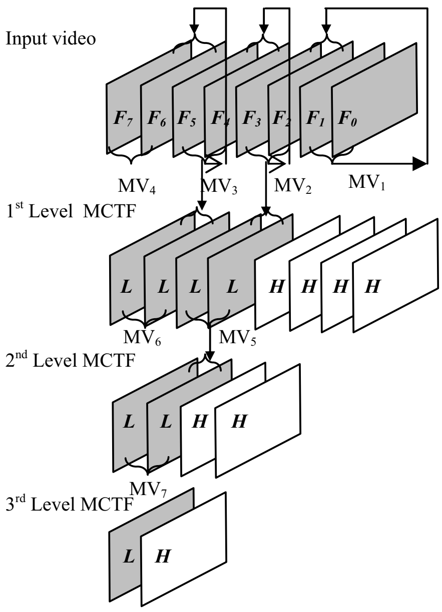

Fig. 4 Predictive motion estimation structure for MCTF

Consider continuous eight frames F0, F1, … F7 (for GOP=8). Among these for the first pair of frames, motion estimation is done by both search step (coarse and fine) that results in motion vector MV1 as shown in Fig. (5). The generated motion vector will be considered as the result of coarse search for the next consecutive pair of frames, that will result in motion vectors MV2, MV3 and MV4. The motion vectors MV2 and MV4 are used to predict motion vectors in the second level (that results in MV5 and MV6) and the motion vector MV5 is used to predict motion vector in the third level (results in MV7) and fine search is done as usual for all motion estimation.

In a GOP of eight frames after three level MCTF there will be seven motion vector sets (i.e. MV_1, MV_2,……MV_7). Among these motion vectors, MV_1 requires 8 bits (in case of window size 15 X 15, for x-coordinate 4-bit and y-coordinate 4-bit) to represent. The remaining motion vectors (i.e. MV_2, MV_3 … MV_7) are found by prediction technique, that requires only 4 bits (result of fine search around ±1 positions of the predicted position). Hence the number of bits required for motion vectors are reduced by 50%, except for the motion vectors of the first pair in a GOP.

IV. Simulation Results

Simulation of the proposed technique is done on MC-EZBC a state-of-the-art scalable video coder [26]. During simulation of the proposed technique we have considered full search motion estimation with 1/8 pixel accuracy, 5/3 wavelet transform for temporal filtering, Debauchees 9/7 wavelet filter for spatial wavelet transform, window size 15 X 15 and block size 16 X 16. Standard test sequences like Akiyo, News, Foreman, etc., of QCIF resolution at 30 frames per second showing all varieties of motions are considered.

Table I
The PSNR Values of Diamond and Predictive Diamond fast block motion estimation techniques for Akiyo test sequence of QCIF resolution for 96 frames and GOP of 8.

Akiyo	Diamond			Predictive Diamond		
kbps	Y	U	V	Y	U	V
250	32.26	34.52	36.64	32.26	34.52	36.64
500	37.60	38.56	39.59	37.60	38.56	39.59
750	41.27	42.09	42.77	41.27	42.09	42.77
1050	44.48	45.75	46.02	44.48	45.75	46.02
1300	47.04	47.05	47.54	47.04	47.05	47.54
1550	48.57	49.28	49.74	48.57	49.28	49.74
1800	50.06	50.95	51.13	50.06	50.95	51.13
2100	51.47	51.73	51.95	51.47	51.73	51.95
2400	52.39	53.00	53.42	52.39	53.00	53.42
2800	52.47	53.15	53.45	52.47	53.15	53.45

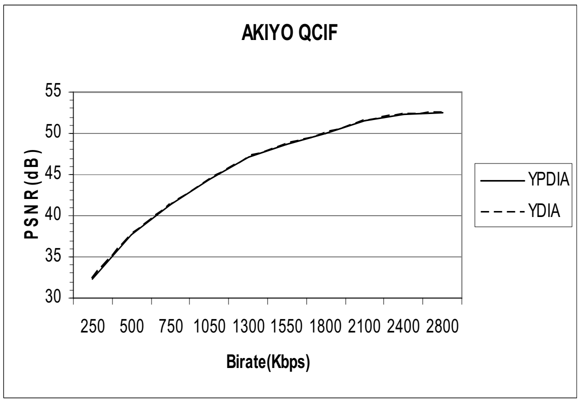

Fig. 5 Comparison of PSNR Value of Diamond and Predictive Diamond for Akiyo Test Sequence of QCIF Resolution

The complete search and predictive search is applied during motion estimation in MCTF and complete encoded bit stream is generated by MC-EZBC. The Table 1 shows the comparison of Diamond and Predictive Diamond when partial decoding is done by extracting (10%, 20%, …) partial bit stream from the encoded bit stream. During complete extraction, at every stage the PSNR values for all the components Y, U and V of Akiyo test video sequence remains same for Diamond and Predictive Diamond as shown in Fig. 5.

The technique performs similarly in case of Hexagon search as shown in Table II and Fig. 6 for Akiyo test sequence.

The technique is tested for various bit rates with high motion and camera pan video CarPhone. In this case also the technique performed well as shown in Table III, IV and Fig. 7, 8.

TABLE II
THE PSNR VALUES OF HEXAGON AND PREDICTIVE HEXAGON FAST BLOCK MOTION ESTIMATION TECHNIQUES FOR AKIYO TEST SEQUENCE OF QCIF RESOLUTION FOR 96 FRAMES AND GOP OF 8.

Akiyo	Hexagon			Predictive Hexagon		
kbps	Y	U	V	Y	U	V
270	32.75	34.52	36.64	32.75	34.52	36.64
545	38.31	39.66	40.35	38.31	39.66	40.35
820	42.05	42.92	43.41	42.05	42.92	43.41
1088	44.85	44.85	46.72	44.85	44.85	46.72
1360	47.28	48.07	48.49	47.28	48.07	48.49
1640	49.10	49.76	50.33	49.10	49.76	50.33
1900	50.63	50.95	51.13	50.63	50.95	51.13
2180	51.68	52.36	52.34	51.68	52.36	52.34
2450	52.45	53.10	53.49	52.45	53.10	53.15
2900	52.47	53.15	53.45	52.47	53.15	53.45

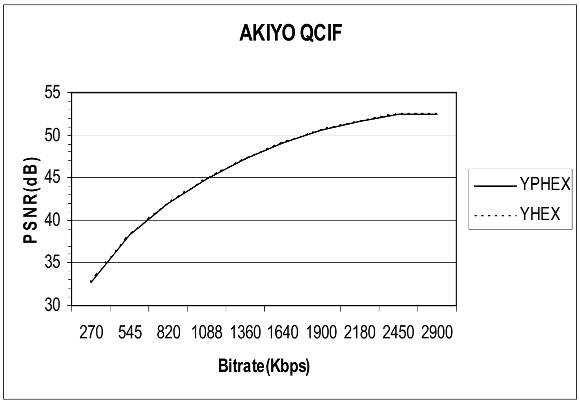

Fig. 6 Comparison of PSNR Value of Hexagon and Predictive Hexagon for Akiyo Test Sequence of QCIF Resolution

The Table V shows the number of search positions in first GOP of various test sequence for Diamond and Hexagon non-predictive and predictive technique. It indicates that in almost all types of motion video the proposed technique performed well. In case of slow motion video Akiyo in Predictive Hexagon 38.24% of reduction is observed and fast video Table Tennis 36.48% of reduction is observed. In case of Predictive Diamond the reduction for Akiyo and Table Tennis is 21.51% and 21.28% is observed respectively. The proposed technique reduces the number of search positions by 20.75% to 38.24% over different standard test sequence and over different fast motion estimation technique as shown in Table V.

TABLE III
THE PSNR VALUES OF DIAMOND AND PREDICTIVE DIAMOND FAST BLOCK MOTION ESTIMATION TECHNIQUES FOR CARPHONE TEST SEQUENCE OF QCIF RESOLUTION FOR 96 FRAMES AND GOP OF 8.

CarPhone	Diamond			Predictive Diamond		
kbps	Y	U	V	Y	U	V
320	32.71	37.26	36.92	32.71	37.26	36.92
640	38.26	40.12	40.38	38.26	40.12	40.38
960	42.10	43.24	43.03	42.10	43.24	43.03
1280	44.77	45.47	46.00	44.77	45.47	46.00
1600	47.25	47.02	47.50	47.25	47.02	47.50
1920	48.71	49.05	49.36	48.71	49.05	49.36
2240	50.49	49.73	50.01	50.49	49.73	50.01
2560	51.53	51.43	50.8	51.53	51.43	50.80
2890	52.25	52.53	52.63	52.25	52.53	52.63
3200	52.28	52.64	52.67	52.28	52.64	52.67

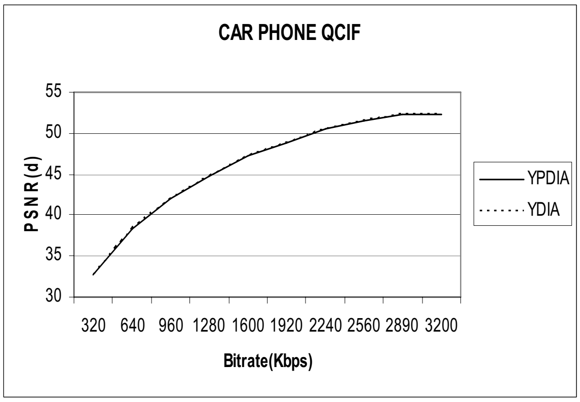

Fig 7 Comparison of PSNR Value of Diamond and Predictive Diamond for Carphone Test Sequence of QCIF Resolution

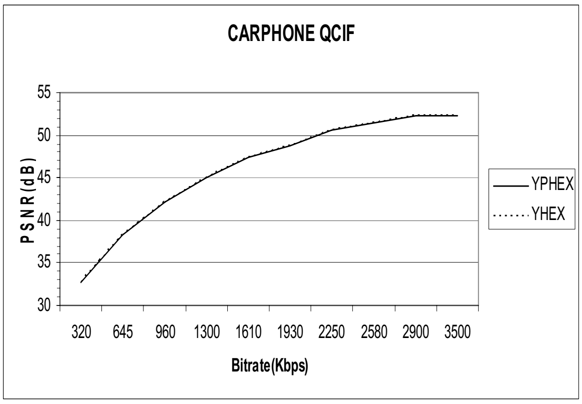

Fig. 8 Comparison of PSNR Value of Hexagon and Predictive Hexagon for Carphone Test Sequence of QCIF Resolution

TABLE IV
THE PSNR VALUES OF HEXAGON AND PREDICTIVE HEXAGON FAST BLOCK MOTION ESTIMATION TECHNIQUES FOR CARPHONE TEST SEQUENCE OF QCIF RESOLUTION FOR 96 FRAMES AND GOP OF 8.

CarPhone	Hexagon			Predictive Hexagon		
kbps	Y	U	V	Y	U	V
320	32.71	37.26	36.92	32.71	37.26	36.92
645	38.32	40.12	40.51	38.32	40.12	40.51
960	42.10	43.24	43.03	42.10	43.24	43.03
1300	45.01	45.47	46.0	45.01	45.47	46.00
1610	47.33	47.02	47.50	47.33	47.02	47.50
1930	48.78	49.05	49.36	48.78	49.05	49.36
2250	50.55	49.73	50.01	50.55	49.73	50.01
2580	51.53	51.51	51.09	51.53	51.51	51.09
2900	52.26	52.53	52.63	52.26	52.53	52.63
3500	52.28	52.64	52.71	52.28	52.64	52.71

The Table VI shows PSNR value for all Y, U & V components in case of all standard test sequences by Diamond and Hexagon predictive and non-predictive techniques at 1024 kbps decoded rate from compressed bit stream.

TABLE V
THE NUMBER OF SEARCH POSITIONS FOR HEXAGON AND DIAMOND FOR VARIOUS STANDARD TEST SEQUENCES FIRST GROUP OF FRAMES ON STANDARD AND PROPOSED TECHNIQUE.

Sequence	Hexagon	Predictive Hexagon (% of reduction)	Diamond	Predictive Diamond (% of reduction)
TableTennis	2387	871(36.48)	3079	649(21.08)
Akiyo	2254	862(38.24)	2937	632(21.51)
GrandMother	2312	864(37.37)	3011	639(21.22)
MotherDaughte r	2248	859(38.21)	2995	636(21.23)
Suize	2256	859(38.07)	3005	641(21.33)
News	2361	870(36.84)	2997	638(21.28)
Foreman	2340	870(37.17)	3041	642(21.11)
Carphone	2314	863(37.29)	2951	633(21.45)
Salesman	2363	878(37.15)	3100	652(21.03)
Coastguard	2427	876(36.09)	3170	658(20.75)
Container	2513	892(35.49)	3087	650(21.05)

V. CONCLUSION

This paper proposed a novel predictive motion estimation structure for MCTF framework. The technique reduces the number of search points by 20.75% - 38.24% compared to non-predictive technique for different fast block motion estimation technique depending on the standard test sequences. The technique will not compromise with the objective or subjective quality of the video. The number of bits required for motion vectors are also automatically reduced drastically. Hence the proposed technique is a candidate for replacing the existing non-predictive MCTF framework.

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TABLE VI
THE PSNR OF VARIOUS QCIF STANDARD TEST SEQUENCE FOR HEXAGON AND DIAMOND SEARCH ALGORITHMS FOR STANDARD AND PROPOSED TECHNIQUE AT 1024 KBPS

Sequence	Hexagon			Predictive Hexagon			Diamond			Predictive Diamond		
	Y	U	Y	Y	U	V	Y	U	V	Y	U	V
Akiyo	44.85	44.85	46.72	44.85	44.85	46.72	44.48	45.75	46.02	44.48	45.75	46.02
News	39.26	40.99	41.77	39.26	40.99	41.77	39.01	40.99	41.77	39.01	40.99	41.77
CarPhone	45.01	45.47	46.0	45.01	45.47	46.00	44.77	45.47	46.00	44.77	45.47	46.00
Foreman	39.26	40.99	41.77	39.26	40.99	41.77	38.94	41.41	41.76	38.94	41.41	41.76
CoastGaurd	37.85	45.26	45.93	37.85	45.26	45.93	37.61	44.59	45.61	37.61	44.59	45.61
Container	39.69	42.46	42.80	39.69	42.46	42.80	39.69	42.46	42.80	39.69	42.46	42.80
GrandMother	41.16	42.62	42.92	41.16	42.62	42.92	40.89	42.62	42.83	40.89	42.62	42.83
MotherDaug.	44.43	46.00	46.79	44.43	46.00	46.79	44.64	46.00	46.78	44.64	46.00	46.78
SalesMan	39.26	40.99	41.77	39.26	40.99	41.77	38.94	41.41	41.76	38.94	41.41	41.76
Suzie	45.43	48.32	48.24	45.43	48.32	48.24	45.39	48.32	48.24	45.39	48.32	48.24
TableTennis	38.15	42.26	40.94	38.15	42.26	40.94	39.51	42.75	41.64	39.51	42.75	41.64