Novel Fast Motion Estimation for Frame Rate/Structure Conversion

Justy W.C. Wong, Oscar C. Au, Peter H.W. Wong***
Department of Electrical and Electronic Engineering
The Hong Kong University of Science and Technology
Clear Water Bay, Hong Kong, China.
Tel: +852 2358-7053 Fax: +852 2358-1485
*Email: eejusty@ee.ust.hk, *eeau@ust.hk, ** eepeter@ee.ust.hk*

Abstract

Different multimedia applications and transmission channels require different resolution, frame rates/structures and bitrate, there is often a need to transcode the stored compressed video to suit the needs of these various applications. This paper is concerned about fast motion estimation for frame rate/structure conversion. In this paper, we proposed several novel l algorithms that exploit the correlation of the motion vectors in the original video and those in the transcoded video. We achieve a much higher quality than existing fast search algorithms with much lower complexity.

1 Introduction

In many networked multimedia services such as web TV, video-on-demand and video-conferencing, most if not all stored video is only available in compressed form due to the huge storage size of video and limited available bandwidth. As different applications and transmission channels require different resolution, frame rates/structures and bit rates, there is often a need to transcode the stored compressed video to suit the needs of these various applications. This paper is concerned about fast motion estimation for frame rate/structure conversion. It is well known that motion estimation is very computationally expensive. Though traditional fast motion searches exit, it is possible to exploit the correlation of the motion vectors in the original video and those in the transcoded video for considerably better performance. In particular, we will address the situation shown in Figure 1 in which a video in IPPP format is to be converted to the IBP format. In this case, frame k is converted from P-frame to B-frame, and frame k+1, a P-frame original predicted with respect to frame k, is to be predicted from frame k-1.

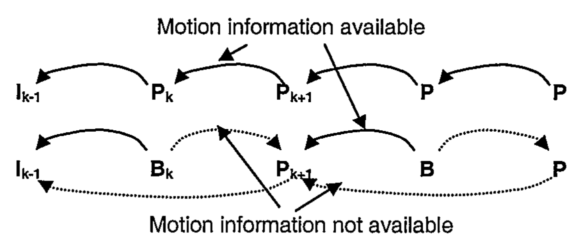


Figure 1 Missing motion information due to a change in frame structure

2 Motion for P-to-B frame Conversion (frame k)

It can be observed in Figure 2 that the backward motion vectors should be highly correlated with the original forward motion vectors. In [2], it was proposed to predict the reverse motion vectors from the forward motion vectors. We will apply the idea here. Consider a macro block $MB_k(x,y)$ at location (x,y). The backward motion vector of $MB_k(x,y)$ should be similar in magnitude to the forward motion vector of $MB_{k+1}(x,y)$ though with opposite sign. Let $v_{k,B}(x,y)$ be the backward motion vector at location (x,y) found by full search for frame k (a B-frame in the IBP format) and let $v_{k+1,P}(x,y)$ be the original forward motion vector at location (x,y) of frame k+1 (a P-frame in the IPPP format). Let $v'_{k,B}(x,y)$ be the predicted version of $v_{k,B}(x,y)$ to be computed. We propose to use the negative value of $v_{k+1,P}(x,y)$ as $v'_{k,B}(x,y)$, i.e.,

$$v'_{k,B}(x,y) = -v_{k+1,P}(x,y) \qquad \text{for all } x,y. \quad (1)$$

However, the $v_{k+1,P}(x,y)$ is not available when frame k+1 is an I-frame (k+1=GOP). In this situation, we use the negative value of $v_{k,P}(x,y)$ as the $v'_{k,B}(x,y)$ which is a poorer prediction than $-v_{k+1,P}(x,y)$. So the equation (1) becomes

$$v'_{k,B}(x,y) = \begin{cases} -v_{k+1,P}(x,y) & \text{for } k+1 \neq \text{GOP}, \\ -v_{k,P}(x,y) & \text{otherwise.} \end{cases} \quad (2)$$

and we called this algorithm P2B.

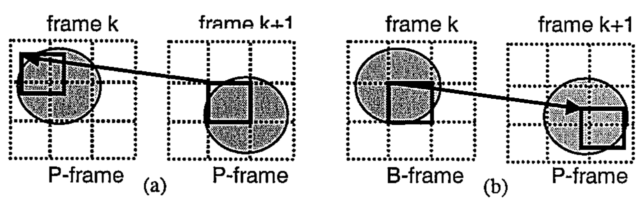
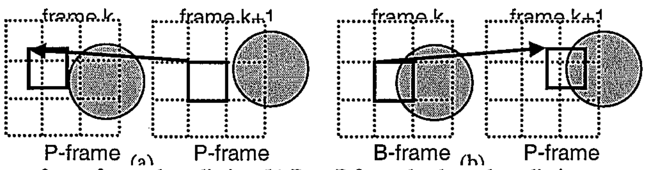


Figure 2. The motion estimation of frame k & k+1 with: (a) P to P-frame forward prediction (b) B to P-frame backward prediction

P2B can give a reasonably good prediction of $v_{k,B}(x,y)$. However, there are situations such as shown in Figure 3 in which it can be poor. In Figure 3, $v_{k,B}(x,y)$ is not related to $v_{k+1,P}$ (x,y) but is actually more related to the motion vector $v_{k+1,P}(x+16,y)$ of the neighboring macroblock, $MB_{k+1}(x+16,y)$. This suggests that the original motion vectors of the neighboring macroblocks can possibly be good prediction. Here we propose to modify P2B by using the $v'_{k,B}(x,y)$ found by P2B and the $v'_{k,B}$ from the eight neighboring macroblocks, which are $v'_{k,B}(x-16,y-16)$, $v'_{k,B}(x,y-16)$, $v'_{k,B}(x+16,y-16)$, $v'_{k,B}(x-$

16,y), $v'_{k,B}(x+16,y)$, $v'_{k,B}(x-16,y+16)$, $v'_{k,B}(x,y+16)$ and $v'_{k,B}(x+16,y+16)$. We compute the MAD of these nine candidate motion vectors and find the best one. We called this modification the P2B with search (P2BS). In order to get a better prediction, an additional half-pixel search can be performed and we called this P2BS-LS (P2BS with local search).

Figure 3. The motion estimation of frame k & k+1 with: (a) P-to-P



frame forward prediction (b) B-to-P frame backward prediction

3 Motion for P-to-P frame Conversion (frame k+1)

Let $v'_{k+1,P}$ (x,y) be the motion vectors of the transcoded P-frame k+1 with respect to the frame k−1. It can be observe in Figure 4 that $v'_{k+1,P}(x,y)$ is close to $v_{k,P}(x',y') + v_{k+1,P}(x,y)$ for some (x',y'). When tracing the object, the predicted block for frame k+1 will usually overlap with four macroblocks in frame k. In this example, as the overlapping region of the predicted block and the macroblock $MB_{k,P}(x,y\text{-}16)$ is the largest, the object in $MB_{k+1,P}(x,y)$ is more likely matched to $MB_{k,P}$ $(x,y\text{-}16)$ than $MB_{k,P}$ (x,y). Let (x',y') be the position of the macroblock in frame k that gives the largest overlapping region with the predicted block associated with $v_{k+1,P}$ (x,y). In [3], forward dominant vector selection (FDVS) is proposed to use $v'_{k,P+1}(x,y) = v_{k,P}(x',y') + v_{k,P+1}(x,y)$. From our simulation results, FDVS can be poor in terms of PSNR when compared with FS. To improve the performance FDVS, [3] performed a refinement search with search area of ±2 pixels performed. However, this refinement search increases the complexity sharply.

Here we propose to use the original motion vectors $v_{k,P}$ of the four macroblocks in the frame k which overlaps with the predicted block associated with $v_{k+1,P}$ (x,y). With the four candidate vectors, we compute the MAD and choose the one with minimum MAD. We called this algorithm P2P with search (P2PS). To get better prediction, an additional half-pixel search can be performed and we called it P2PS-LS.

So far, the discussion is on changing a IPPP structure to an IBP structure. Actually, the proposed algorithms P2B, P2BS, P2BS-LS, P2PS, P2PS-LS can be used for frame-rate reduction also.

4 Different Frame-Rate Reduction Rate

In section 2 & 3, we proposed several fast motion estimation algorithms to predict the motion vectors for frame-rate reduction by 1/3. In figure 5, the frame-rate of the video sequence is reduced by ½. As frame P_2 is dropped, all the motion vectors refer to this frame need to be re-estimated which are V'_{Br2}, V'_{Bf3} and V'_{P3}. P2PS and P2PS-LS can predict V'_{Bf3} and V'_{P3}. Moreover, we can predict V'_{Br2} by combining the V_{Br2} and V_{P3}. There are many different combinations of V_{Br2} and V_{P3} by using our proposed algorithms, e.g. (1) use the P2BS to find the reverse version of V_{P3} between frame P_2 and frame P_3 and then use P2PS to combine the V_{Br2} and reverse V_{P3}; (2) combine the candidate motion vectors of P2PS and P2BS together and directly predict between frame B_2 and P_3. That means we use each of the four candidates in P2PS plus the nine candidates in P2BS as the motion vectors and search between the frame B_2 and P_3 by all together maximum 36 candidate motion vectors. The combination (2) is preferred because it is directly predict between the frame P_3 and B_2 but it requires higher complexity (1), which only needs maximum 13 candidates search. We can also further generalize these algorithms to adapt different frame-rate reduction rate by optimizing these combinations.

5 Simulation Results

We tested our algorithms against full search (FS) and three-step-search (3SS) by converting several MPEG I video sequences with SIF resolution (352×240) and a GOP of 30 frames from the IPPP frame structure in each GOP into IBP frame structure. The search window is ±7. The performance measure is the peak-signal-to-noise-ratio (PSNR in dB) between the motion compensated frames and the original frames.

Some results of P-to-B conversion are shown in Table 1-3 and Figures 5. From the graphs, we can see that the performance of P2BS-LS is much better than 3SS and can be very close to full search for all test sequences.

Some results of P-to-P conversion are shown in Table 4-6 and Figure 6. From the tables, FVDS has higher PSNR than 3SS in "Table Tennis" and "Miss America", but lower in "Football" and "Salesman". The refinement of FVDS (FVDS-R) improves much in PSNR but it needs about many (23) average search points in all cases. On the other hard, the proposed P2PS has similar PSNR as FVDS-R with much lower complexity. The local search of P2PS-LS can significantly improve the PSNR by 0.8dB in the cases of "Table Tennis" and "Salesman", making the final PSNR very close to that of FS-14. Actually, P2PS-LS has higher PSNR than FS-7 while requiring much fewer search point than FS-7 and FS-14. Moreover, P2PS-LS has higher PSNR than FVDS-R by about 0.3 to 0.6 dB and with only 1/3 of the average points of FVDS-R.

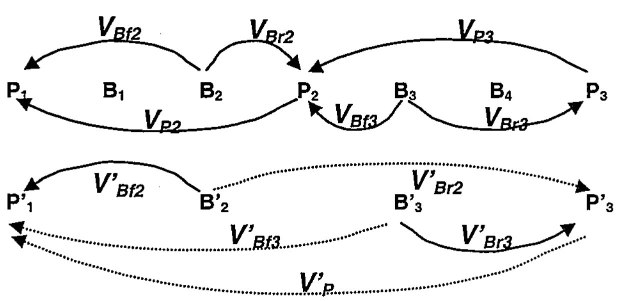


Figure 5. Frame-rate reduction by ½

5. Conclusions

In this paper, we proposed two algorithms the P2B and P2BS for the estimation of backward motion vectors for the P-to-B frame conversion. We also proposed the P2PS for the estimation of motion vectors for the P-to-P frame conversion. The performance of the proposed algorithms is much better than the 3-Step-Search with much lower computation load. The proposed algorithms can achieve various quality and complexity tradeoff. In particular, the P2BS-LS and P2PS-LS have close to optimal performance with very small computation requirement. Moreover, the proposed algorithms can be combined and used for frame-rate reduction also.

6 References

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[2] S. J. Wee, "Reversing Motion Vector Fields", *Proc. of 1998 IEEE Int. Conf. Image Processing*, Chicago, USA, Oct. 1998.

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	Football		Table Tennis		Salesman		Miss America		Foreman		Coast Guard		News	
	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	Pts
3 SS	24.39	25	25.60	25	35.39	25	38.54	25	30.64	25	29.93	25	36.39	25
3 SS half pel	25.15	25+8	26.82	25+8	36.00	25+8	39.91	25+8	32.05	25+8	30.73	25+8	37.18	25+8
P2B	23.96	–	27.43	–	35.57	–	39.03	–	30.90	–	30.31	–	36.20	–
P2BS	24.92	5.44	28.93	3.40	36.00	2.55	39.56	2.34	31.88	4.29	30.75	3.20	36.88	1.67
P2BS-LS	25.20	12.86	29.13	9.28	36.12	8.93	40.31	9.76	32.35	11.33	30.90	10.44	37.13	9.08
FS-7	25.50	225+8	29.33	225+8	36.17	225+8	40.34	225+8	32.55	255+8	30.93	255+8	37.37	255+8

Table 1. Average PSNR (in dB) of the predicted frame using different algorithms for the backward prediction

	Football		Table Tennis		Salesman		Miss America		Foreman		Coast Guard		News	
	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts	PSNR	pts
3 SS-14	23.02	33	36.75	33	28.58	33	26.79	33	33.04	33	37.76	33	23.53	33
3 SS half pel	23.61	33+8	37.56	33+8	29.44	33+8	27.53	33+8	33.78	33+8	38.94	33+8	24.31	33+8
FVDS	22.45	-	35.88	-	29.19	–	27.92	–	33.35	–	37.95	-	25.59	-
FVDS-R	23.06	23.35	37.16	23.04	29.80	23.28	28.08	23.39	33.68	23.02	38.66	23.09	25.96	23.02
P2PS	23.12	2.14	36.68	0.65	29.55	2.18	28.03	1.99	33.55	0.31	38.18	0.81	25.95	1.35
P2PS-LS	23.55	8.43	37.47	8.06	30.25	9.71	28.57	9.53	33.99	7.71	39.25	8.24	26.71	7.54
FS-7	23.23	225+8	37.80	225+8	29.59	255+8	28.49	255+8	33.95	255+8	39.55	225+8	26.61	225+8
FS-14	24.37	841+8	37.85	841+8	30.63	841+8	28.61	841+8	34.28	841+8	39.58	841+8	27.07	841+8

Table 2. Average PSNR (in dB) of the predicted frame using different algorithms for the P frames

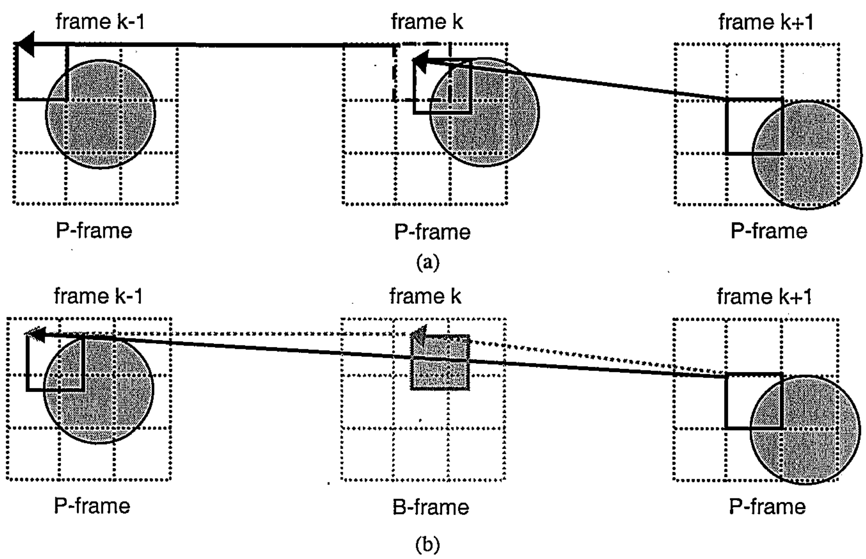
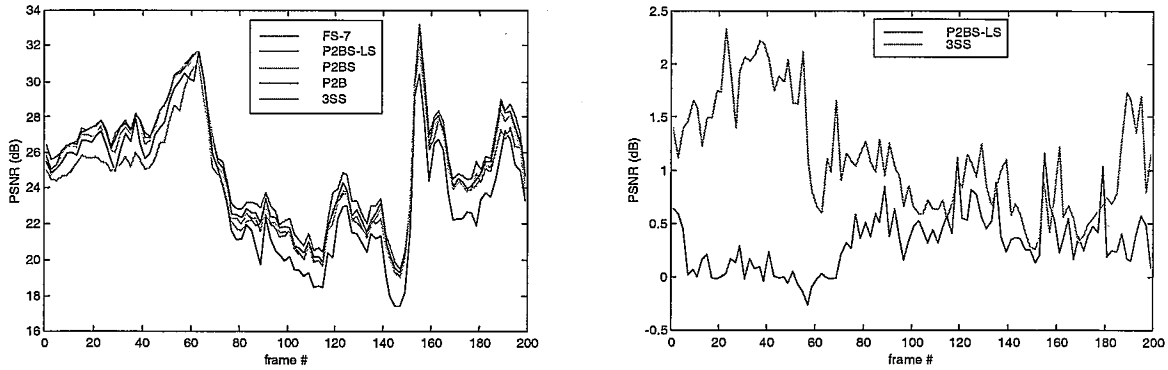
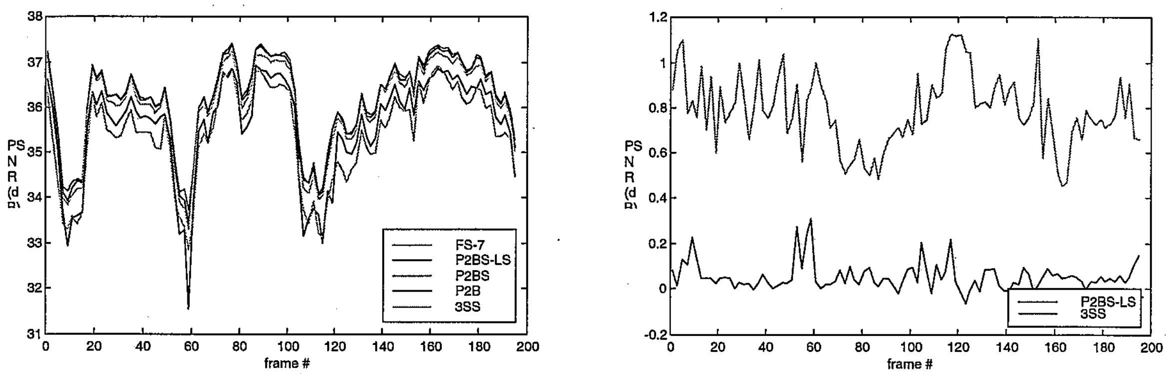


Figure 4 The forward motion estimation of frame k-1, k & k+1 with: (a) original P-frame forward prediction (b) re-encoded P-frame forward prediction



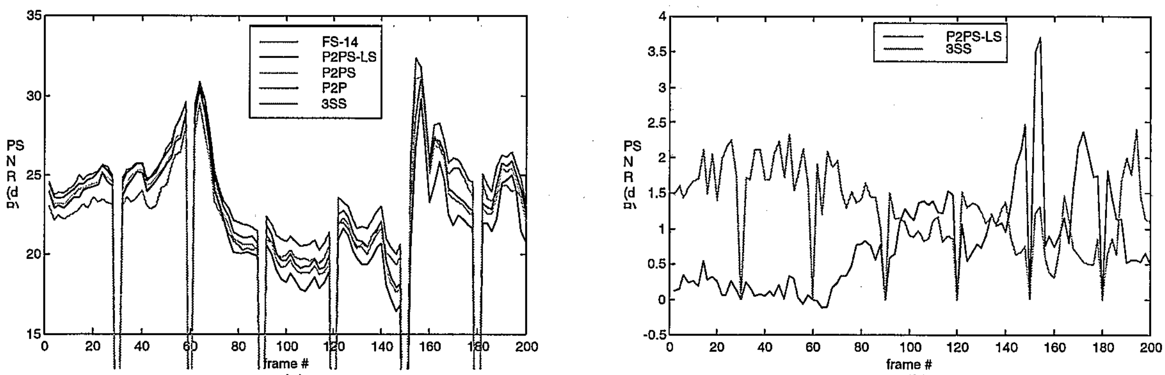
(a) (b)

Figure 6. (a) PSNR of predicted B-frames using different algorithms; (b) PSNR of full search minus that of P2BS-LS and 3SS for "Football"



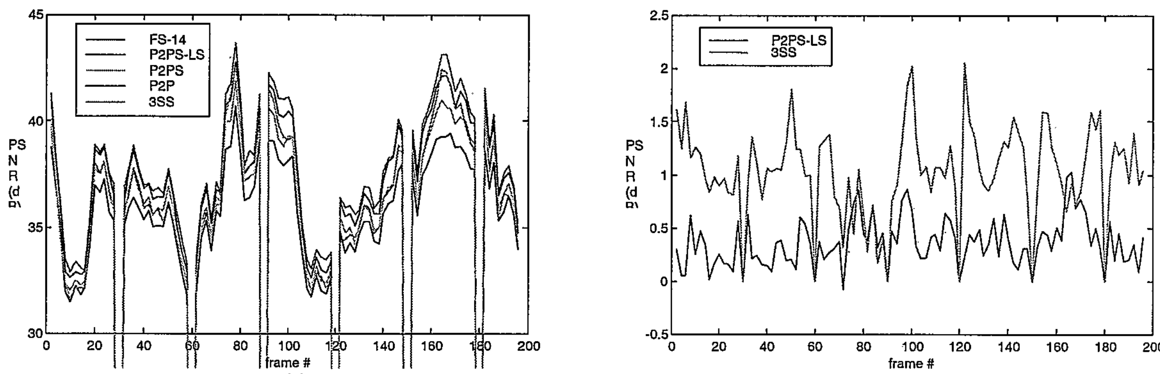
(a) (b)

Figure 7. (a) PSNR of predicted B-frames using different algorithms; (b) PSNR of full search minus that of P2BS-LS and 3SS for "Salesman"



(a) (b)

Figure 8. (a) PSNR of predicted P-frames using different algorithms; (b) PSNR of FS-14 minus that of P2PS-LS and 3SS for "Football"



(a) (b)

Figure 9. (a) PSNR of predicted P-frames using different algorithms; (b) PSNR of FS-14 minus that of P2PS-LS and 3SS for "Salesman"