A Predictive Parallel Motion Estimation Algorithm for Digital Image Processing

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Abstract

This paper presents an efficient Block Matching Algorithm(BMA) for motion estimation. This BMA exploits motion correlation of neighbor blocks in temporal direction as to reduce the search area. Instead of finding 2-D motion vector directly, this BMA finds two 1-D displacements in parallel on two axes independently within the reduced search area. Simulation results show that this algorithm can rival those conventional BMA's for performance. Furthermore, the hardware-oriented features of this BMA guarantee that it is more suitable for hardware realization of a VLSI motion estimator.

I. Introduction

In digital image processing, e.g., video conferencing application, the significantly high correlation between consecutive frames can be exploited more efficiently by considering the displacements of moving objects in the coding process. Therefore, in any motion-compensated coding scheme, the performance of the real-time system heavily depends on the accuracy and speed of the motion estimation.

Comparing with the pel recursive algorithms, the block matching algorithm(BMA) is much more realizable according to its computational simplification [3]. However, one difficulty with the BMA is the extensive computations required by the full search(FS). To alleviate the computational overhead of the FS, several techniques such as the three-step hierarchical search (3SHS) [6], the one-at-a -time search(OTS) [2] and the 2-D logarithmic search(LOGS) [1] have been developed. Recently, some researchers [9] point out that if the temporal correction of the motion vectors were well employed, the computational complexity could be reduced dramatically. However, they encountered irregular control flow when hardware realization is considered.

The objective of this paper is to propose an efficient hardware-oriented BMA, which involves considerably simpler arithmetic and regular control flow. The search procedure and properties of the proposed algorithm are described in Section II. The simulation results from four measurements on a video sequence are reported in Section III. Conclusions are presented in Section IV.

II. The Proposed Algorithm

To reduce the computational complexity, all the conventional BMA's assume that the distortion increases monotonically as the searched point moves away from the direction of minimum distortion [5]. However, they neglect one significant property of video sequence, that is the correlation of the motion vectors between two neighbor blocks in the temporal direction. Due to the continuity of motion in temporal direction, the motion vector(MV) of the current block, say $B_t(u,v)$ (where u,v are spatial indices and t is temporal index), could be predicted from the MV of the previous block $B_{t-1}(u,v)$. Therefore, the search area of $B_t(u,v)$ could be reduced according to the direction of the MV of $B_{t-1}(u,v)$. Under the above assumption made by the conventional BMA's, we need not make too much effort to find out the exact two-dimensional displacement of the moving object. Therefore, a more efficient algorithm, predictive parallel one-dimensional search algorithm (PPHODS), can be desired. The word "*predictive*" means this algorithm can predict the MV of the current block from that of the previous block. The word "*parallel hierarchical one-dimensional search*" means that the algorithm can hierarchically locates two one-dimensional displacements in parallel on two axes(say x and y) independently within the reduced search area. The MV $(\Delta x,\Delta y)$ of $B_t(u,v)$ is obtained from the results of the x-axis search $(\Delta x,k)$ and the y-axis search $(h,\Delta y)$ concurrently, where (h,k) is the MV of $B_{t-1}(u,v)$. The mean absolute error(MAE) is chosen as the matching criterion [3][4] because of its simpler computational complexity [2].

The graphical illustration of the PPHODS is shown in Fig.1. Its searching procedures is described as follows:

INITIALIZATION:

/* assume current block is $B_t(u,v)$ */

input the MV (h,k) of previous block $B_{t-1}(u,v)$;

$S=2^{\lfloor \log_2 p' \rfloor}$;

/* p' is the maximum displacement limited in the reduced search area, e.g. p'=3 for p=7 */

/* $\lfloor \cdot \rfloor$ is a lower integer truncation function */

$\Delta x=h$; $\Delta y=k$;

/* use (h,k) as an initial guess in search procedure */

BEGIN SEARCH LOOP:

while (S is larger than zero)

DO IN PARALLEL

/* calculate MAE's for the search points */

x-axis : $(\Delta x,k)$<-- the location of min

$(D(\Delta x-S,k),D(\Delta x,k), D(\Delta x+S,k))$;

y-axis : $(h,\Delta y)$<-- the location of min

$(D(h,\Delta y-S),D(h,\Delta y), D(h,\Delta y+S))$;

S=S/2;

END SEARCH LOOP;

the ***MV*** of the current block $B_t(u,v)$ is $(\Delta x,\Delta y)$.

Table I presents the theoretical comparison of the required number of search points and sequential steps of the algorithms mentioned above. It is clear that the PPHODS can provide better performance either in number of searching points or in number of steps. Furthermore, the PPHODS also possesses some important features: 1) *regularity*: static sequential steps and regular data flow can easily done hardware implementation.; 2) *simplification*: the less required number of search points per sequential step and the reduced search area caused by predictive mode can lower the computational overhead; 3) *parallelism*: the x- and y-axis searches could be parallel processed to shorten the searching time.

Finally, the only penalty of such predictive fashion using in the proposed BMA is just needed an extra buffer to store all the MV's within a frame.

III.Simulation Results and Performance Comparisons

To test the performance of the PPHODS, a sequence (a speaker with slow movements) containing 16 frames with a frame sampling rate at 12.5 Hz, and each frame possessive of 256*256 pels and 8-bit resolution for each pel, is used in the simulation. The simulation is performed on an IBM PC/AT personal computer. The comparisons are made on five search algorithms, namely i)FS ii)3SHS iii)LOGS vi)OTS v)PPHODS, in terms of the following four measures: 1)PSNR(peak-to-peak SNR), shown in Fig.2; 2)entropy, shown in Fig.3; 3)the percentage of unpredictable pels[2], shown in Fig.4; 4)search time(CPU time), shown in Fig.5. As the experimental results summarized in Table II, it has been proven that the PPHODS algorithm indeed provide better performance with shorter searching time as expected.

IV. Conclusions

In this paper, an efficient parallel search algorithm (PPHODS) is presented for motion estimation. The proposed algorithm needs simple procedure and hardware, but provides better performance than other previous techniques. Most of the hardware proposed recently is applicable to the FS only [7] [8], since the search strategies require a control overhead for the non-regular dataflow and will delay the search times for the motion vectors caused by the hardware latency. Due to the parallelism of the PPHODS, the inherent problem of the discontinuity of the search strategies existed in the conventional BMA's can be overcome. Furthermore, the regularity, simplification and parallelism of the PPHODS strongly imply that it is quite suitable for and efficient in VLSI implementation when used as a low bit -rate video coder. A systolic architecture based on the PPHODS is currently under development for real-time motion estimation.

V. References

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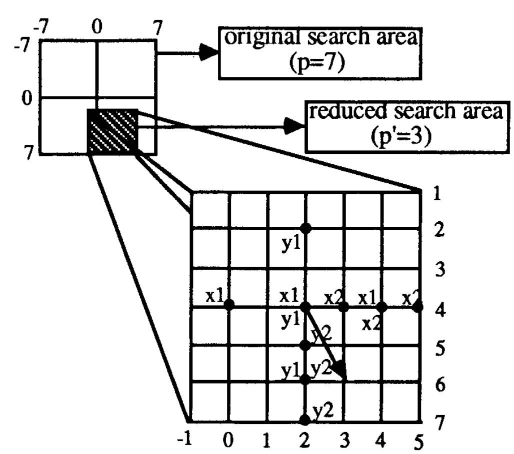

Fig. 1. The predictive prallel hierarchical one-dimensional search procedure.The motion vector is (3,6) in this example.

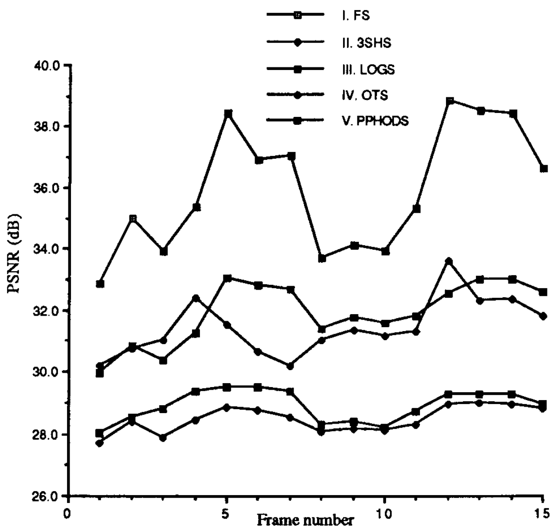

Fig. 2. PSNR comparison on prediction errors for BMA's I-V.

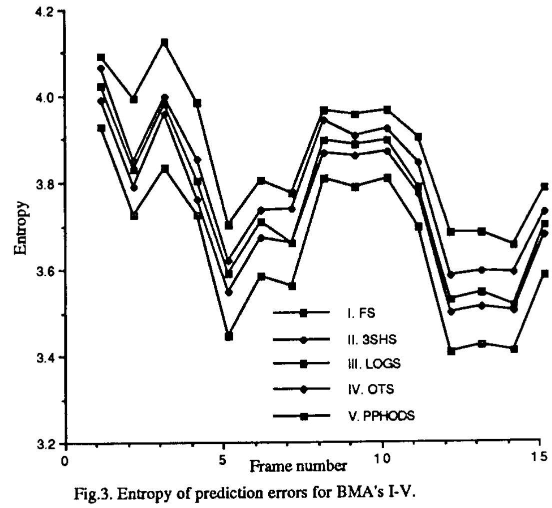

Fig.3. Entropy of prediction errors for BMA's I-V.

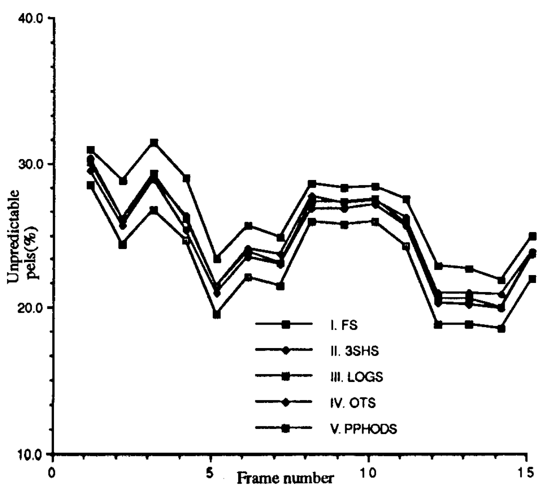

Fig. 4. Unpredictable pels in prediction for BMA's I-V.

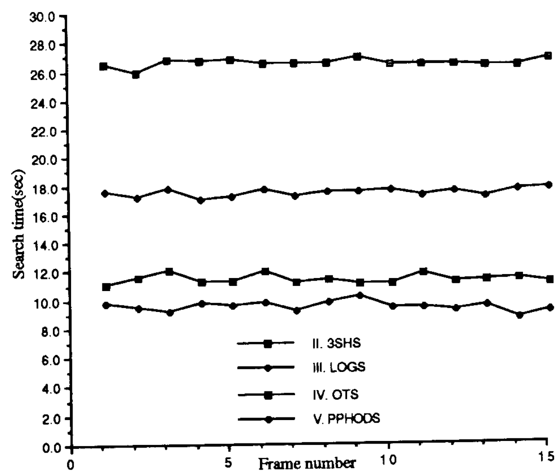

Fig. 5. Search time for BMA's II-V on IBM PC/AT computer.

* The search time of PPHODS should be reduced by 1/2, when parallel processing is considered.

case / algorithm	examples in Fig. 1-5		worst case for p=7	
	a		b	a
II.3SHS	3	25	3	25
III.LOGS	6	22	8	28
IV.OTS	11	14	14	17
V.PPHODS	2	9	2	9

a) Required number of sequential steps.
b) Required number of search points.

Table.I. Comparisons of the number of sequential steps and search points for algorithms II-VI.

Measure / BMA	PSNR (dB)	Entropy	Unpredictable pels(%)	Search time (sec)
I. FS	35.93	3.63	22.77	225.3
II. 3SHS	31.44	3.72	24.09	26.1
III. LOGS	28.90	3.74	24.47	17.0
IV. OTS	28.46	3.78	24.69	11.0
V. PPHODS	31.91	3.85	26.33	* 9.06

Table. II. Comparison of average results for 16 sucessive frames.

* The search time of PPHODS should be reduced by 1/2, when parallel processing is considered.