Sub-Optimal Quarter-Pixel Inter-Prediction Algorithm (SQIA)

Hoi-Ming Wong, Oscar C. Au, Jinxin Huang, Shiju Zhang, Winnie N. Yan
Department of Electrical and Electronic Engineering
The Hong Kong University of Science and Technology
Email: hoimingw@ust.hk, eeau@ust.hk, cstom@ust.hk, ee_zsj@stu.ust.hk, winniey@astri.org

ABSTRACT

Motion Estimation (ME) is an important part of modern video coding systems to exploit temporary redundancy in a video. Motion Estimation is typically performed firstly with integer pixel accuracy and then at sub-pixel accuracy, which includes half-pixel and quarter-pixel accuracy. When sophisticated fast integer-pixel accuracy motion-search algorithms are used to decrease the number of search points for integer-pixel motion search, thus quarter-pixel motion search became another important processing bottleneck in the encoding process. The conventional method is to search 8 half-pixel positions around the Motion Vector (MV) obtained from Integer pixel Motion Search, then do motion search in the same way on 8 quarter-pixel positions around the MV obtained from half-pixel motion search, therefore totally 16 search points are needed. The proposed algorithm, named Sub-Optimal Quarter-Pixel Inter-Prediction Algorithm (SQIA), successfully optimizes the quarter-pixel motion search part and improves the processing speed with low PSNR penalty.

1. INTRODUCTION

In modern video coding standard such as H.261/3/4 [2] and MPEG-1/2/4, block matching motion estimation (BMME) and compensation is done to exploit the temporal correlation and to reduce the redundancy between adjacent frames in video sequences so as to achieve high compression efficiency. In the latest standard H.264, BMME is performed in quarter-pixel accuracy rather than in integer-pixel as in older standards. Quarter-pixel accuracy is especially useful for low bit-rate video coding. The most common distortion measure used in BMME is the sum of absolute difference (SAD) [3], which requires no multiplication and can achieve similar performance as the mean square error (MSE).

Sub-pixel motion estimation and compensation is useful if an object in a video does not move in integer-pixel displacement. If it moves to some half pixel locations which is quite probable, half-pixel motion estimation and compensation would be needed. Half-pixel motion search usually provides much better matching compared with integer-pixel motion search. So in this paper, we assume that half-pixel motion search is always done and we only focus on quarter-pixel motion search. In the conventional brute force quarter-pixel search, 8 quarter-pixel positions are searched around a selected half-pixel position with lowest SAD for each search block. For a frame of size P x Q and a frame rate of T fps, the amount of computation (addition) for full quarter-pixel search (FQPS) is:

$$8*T*[(P \times Q)/(N*N)]*(2N^{2}-1) \text{ op/sec}$$

For T = 30, P = 352, and Q = 288 which is CIF format, this amounts to 4.8×10^{7} operation/s. Note that this has not included the computation needed to compute the sub-pixel values. FQPS can consume up to 30% of the total computational power of an encoder when sophisticated fast integer-pixel motion search such as PMVFAST is used.

Two existing fast sub-pixel motion search algorithms are PPHPS [1] and 2SS [4] that can reduce the total search points from 8 to 3 or 4 for each search block. In this paper, we propose a new fast quarter-pixel search algorithm called sub-optimal quarter-pixel inter-prediction algorithm (SQIA) which reduces computational complexity by skipping some quarter-pixel motion search situations with little PSNR penalty at the frame and search block levels.

In section 2 we will first introduce the FQPS algorithm. In section 3 we will discuss the algorithm we chose for integer-pixel motion search, which is performed prior to the proposed SQIA. Three levels of SQIA algorithm, namely frame level skipping, block level skipping and search point level prediction, will be introduced in section 4. In section 5 we will show some simulation results and comparisons.

2. FULL QUARTER-PIXEL SEARCH (FQPS)

Let I be the integer-pixel position obtained from integer-pixel motion search. Let h1, h2, h3, …, h8 be the eight half-pixel positions around I. FQPS computes the SAD for all these 8 positions as shown in Fig. 1 and find the best one, say h2, with lowest SAD. Then it computes the SAD for the eight quarter-pixel positions q1, q2, q3, …, q8 around the best half-pixel location. Finally, the position, say q8, with lowest SAD is chosen.

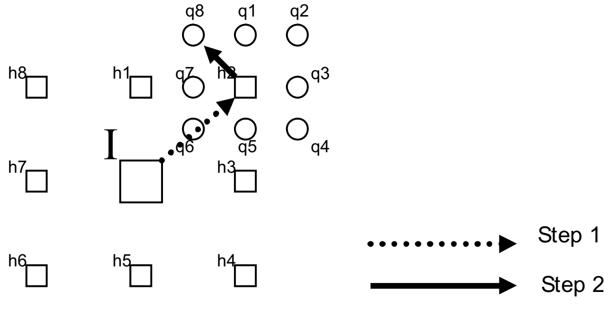

Figure 1 An illustration of FQPS

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3. REQUIREMENT OF INTEGER-PIXEL MOTION SEARCH ALGORITHMS

The proposed SQIA algorithm needs information from integer-pixel motion estimation (IME). The performance of IME can affect the performance of SQIA. In this paper, we use PMVFAST [3] for IME because the resulting motion field tends to be smoother and less noisy than brute force integer-pixel full search with essentially similar perceptual quality. Also, unlike other sub-pixel motion search algorithms, SQIA requires only the final integer motion vector (MV) for each search block. Thus full search is not necessary for IME. Fig. 2(a) shows the motion field of full search which is chaotic, and Fig. 2(b) shows the motion field of PMVFAST [5] which is smoother and more reasonable.

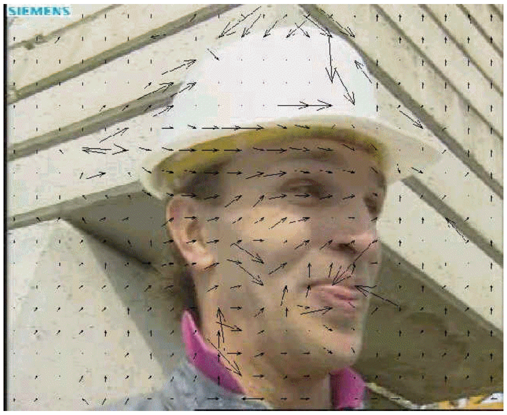


Figure 2(a) Motion Field of Full Search

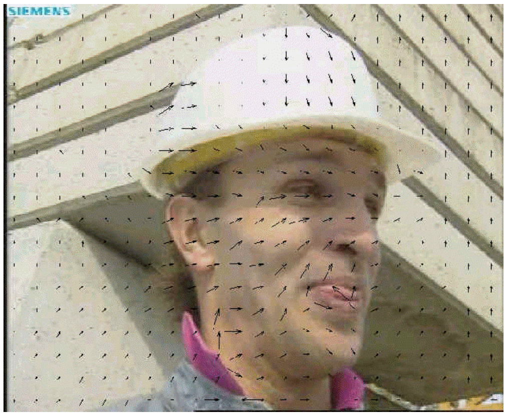


Figure 2(b) Motion Field of PMVFAST

4. SUB-OPTIMAL QUARTER-PIXEL INTER-PREDICTION ALGORITHM (SQIA)

The proposed SQIA algorithm speeds up the quarter-pixel motion search by 3 strategies: frame level skipping, search block level skipping, and search point level prediction. Fig. 3 shows the diagram of the block diagram of SQIA.

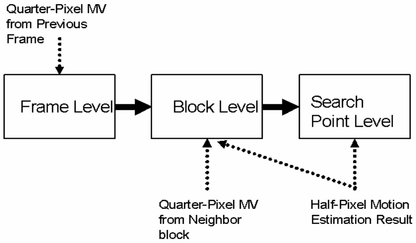

Quarter-Pixel MV from Previous Frame
Frame Level
Block Level
Search Point Level
Quarter-Pixel MV from Neighbor block
Half-Pixel Motion Estimation Result

Figure 3 The proposed SQIA algorithm Diagram

4.1 Frame Level Skipping

We observe in our experiments that in some pictures, such as stationary scenes or pictures with many smooth regions, most final motion vectors in FQPS point to integer-pixel or half-pixel positions rather than quarter- pixel positions. We will call these integer-pixel or half-pixel location motion vectors *None-Quarter-Pixel-MV* (NQMV). An example is shown in Fig. 4 in which white squares are the only moving zones, and the remaining areas are stationary. In this picture, most blocks have zero (integer-pixel) motion vectors. Typically, a few consecutive frames would have a large amount of NQMV. For such frames, the SAD penalty tends to be minimal if quarter-pixel motion search is skipped for the entire frame. This motivates our frame-level skipping.

So if the number of NQMV in the previous frame is greater than a threshold, SQIA would skip the quarter-pixel motion estimation for the entire current frame. (Note that we are NOT skipping integer-pixel or half-pixel motion search.) A problem of perpetual skipping can occur because once quarter-pixel motion search is skipped in a frame, NQMV will be greater than the threshold and frame-level skipping can continue indefinitely in subsequent frames. To prevent such perpetual skipping, we do not allow frame-level skipping to be applied to two consecutive frames. The pseudo code of frame-level skipping is:

```
For each search frame {
    If NQMV of prev. frame < T and prev. frame not skipped {
        Skip quarter-pixel motion search for current frame.
    }
}
```

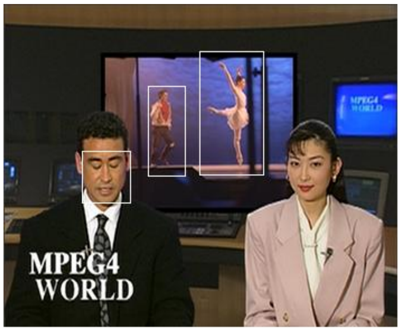


Figure 4 Frame 15 of News_cif sequence

4.2 Search Block Level Skipping

Block level skipping is used in SQIA to skip quarter-pixel motion search for some special stationary blocks within a frame. We observe in our experiments that blocks in a stationary region tend to have zero motion vector. Thus if the three neighboring blocks (left, top and top-right blocks) have zero motion vectors and the current block has zero half-pixel-precision motion vector, the quarter-pixel motion search can be skipped for the current block without much penalty. An example of such blocks is shown in Fig. 5 in which the block marked as C is the current search block and those marked as N are its neighboring block. The pseudo code of search block level skipping is:

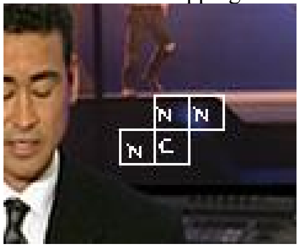


Figure 5 A part of Frame 15 of News_cif sequence

```
For each search block {
   If |Half-Pixel MV| of current block == 0
        And |MV| of Left neighboring block == 0
        And |MV| of Top neighboring block == 0
        And |MV| of Left-Top neighboring block == 0 {
        Skip the Quarter-Pixel Motion Search for Current Block.
   }
}
```

4.3 Search Point Level Prediction

Some existing papers about sub-pixel motion estimation points out that the SAD distribution around the final minimum position is an inverted bell sharp [1] [4]. The proposed algorithm SQIA aims to find the minimum position efficiently. At this stage, SAD for 8 half-pixel positions and the center integer-pixel position are available for the prediction of the minimum quarter-pixel position. Figure 6 shows a typical SAD surface within ± 1 pixel around the global minimum position.

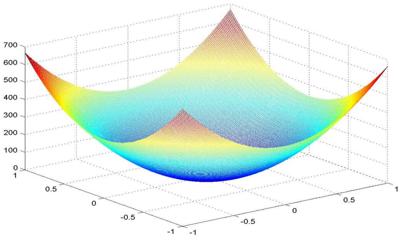


Figure 6 a typical SAD surface

After the frame-level and block-level skipping, there are still blocks to which quarter-pixel motion search needs to be applied. SQIA aims to find the optimal or sub-optimal position efficiently by performing search point prediction.

Some researchers on sub-pixel motion estimation point out that the SAD distribution around the final minimum position tend to have an inverted bell shape [1] [4]. Fig. 6 shows such a typical bell-shaped SAD surface within ± 1 pixel around the global minimum position. Assuming that the SAD for the 8 half-pixel positions and the center integer-pixel position are available for the prediction of the minimum quarter-pixel position, the SAD surface can be modeled as a parabolic function [1]:

$$SAD\ (x,y) = a(x-x_p)^2 + b(y-y_p)^2$$

where p is the point with the lowest SAD. However, computing the minimum point using this equation requires too much computation.

In this paper, we propose a simpler way to predict and search for the minimum point. Again, we assume that the SAD for the 8 half-pixel positions and the center integer-pixel position are available. After locating the optimal half-pixel position with the lowest SAD, SQIA performs searching only at quarter-pixel positions between h3 and its neighboring half-pixel position with 2nd, 3rd and 4th small SAD. In the example in Fig. 7, h3 is the half-pixel position with the lowest SAD, and h2, h5, and h4 are half-pixel positions with the 2nd, 3rd, and 4th lowest SAD. Thus SQIA would compute the SAD at q1, q6, q5.

However, in this way, the outer layer of quarter-pixel locations at horizontal or vertical distance of ¾ from the integer-pixel location I will never be examined, which is unreasonable. So in SQIA, one or two outer layer quarter-pixel locations would also be examined. For example, if the best half-pixel location is h3, one additional outer layer location q3 would also be examined. And similarly, one additional location would be examined for h1, h5 and h7. If the best half-pixel location is h2, two additional outer layer locations – the one to the right and the one to the top of h2 – would be examined. Similar, two additional outer layer locations would be examined for h4, h6 and h8. Note that we have intentionally left out the four corner locations. We observe in our experiments that less than 0.1% of all final quarter-pixel accuracy motion vectors would use the four corner locations. Thus we skip the four corner locations permanently, with little SAD penalty. The total number of quarter-pixel locations examined ranges from 3 to 5. The accuracy of our prediction is checked in our experiments, and the results are shown in Table 1. In most of the cases, we manage to find the optimal quarter pixel motion vector.

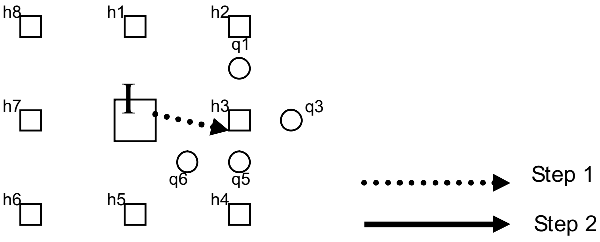


Figure 7 An example of Search Point Level Prediction

Sequence	Prediction Accuracy Rate
News_cif	95.50%
Foreman	92.35%
weather	98.01%
table	87.20%
sean_cif	98.80%
Akiyo	98.30%
Stefan	85.50%

Table 1 Probability of finding the optimal quarter-pixel location

As each level of SQIA is independent, every level can be implemented separately to provide trade off options between processing speed and PSNR loss for different applications.

5. SIMULATION RESULTS

The proposed SQIA algorithm was embedded into the H.264 JM5.0 encoder and was tested using Intel Pentium 4 PC. Table 2 shows the comparisons between the proposed SQIA and 2SS [3] in speed up factor and their corresponding PSNR for various video testing sequences. The simulation results show the proposed SQIA algorithm performs well especially in low motion sequences. Compared with FQPS, SQIA achieves a speed up factor ranging from 2.1 to 15.7, which can be significantly higher than 2SS. The PSNR loss of SQIA compared with FQPS ranges from 0.08 to 0.34dB, which is slightly larger than 2SS.

Some statistics including the frame level skipping percentage, block level skipping percentage and point level search points are shown in Table 3 for different test sequences. For high motion sequences such as Foreman and Stefan, no frame level skipping occurs. For slow sequences such as Weather and Sean, quarter-pixel motion search is skipped in more than 10% of the frames.

For those frames that are not skipped, quarter-pixel search is skipped in up to 80% of the blocks in the slow sequences (with many stationary blocks). However, in high motion sequences with very few stationary blocks, the percentage is much lower at about 10-15%. These are expected because block-level skipping would only skip stationary blocks.

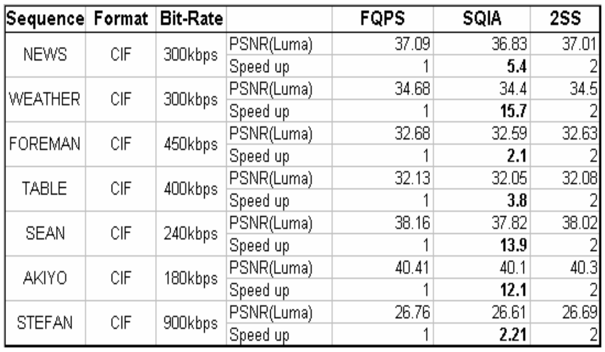
As expected the number of quarter-pixel points examined range from 3 to 5. Fewer points are examined in slow sequences than in high motion sequences.

5.3 Implementation of SQIA

Unlike some algorithms, SQIA does nott contain any complex formula so it is easy for implementation and has very small overhead. Also as each level of SQIA is independent, so every level can be implemented separately to provide trade off options between processing speed and PSNR loss for different applications.

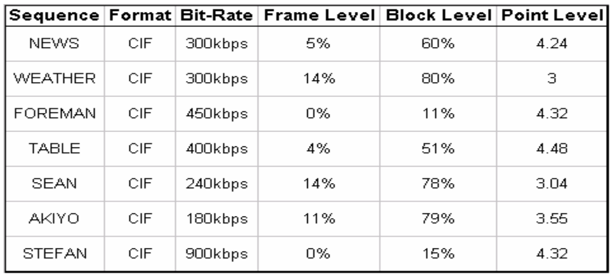
6. CONCLUSION

In this paper we proposed a new fast quarter-pixel motion search algorithm called Sub-Optimal Quarter-Pixel Inter-Prediction Algorithm (SQIA). The algorithm is divided into 3 levels: Frame Level, Block Level and Search Point Level. SQIA is easy to implement and cost-effective. Simulation results show that the proposed SQIA can achieve significant improvement on processing speed over FQPS with small PSNR penalty. Compared with 2SS, SQIA provides different speed-PSNR trade-off.



Sequence	Format	Bit-Rate		FQPS	SQIA	2SS
NEWS	CIF	300kbps	PSNR(Luma)	37.09	36.83	37.01
			Speed up	1	**5.4**	2
WEATHER	CIF	300kbps	PSNR(Luma)	34.68	34.4	34.5
			Speed up	1	**15.7**	2
FOREMAN	CIF	450kbps	PSNR(Luma)	32.68	32.59	32.63
			Speed up	1	**2.1**	2
TABLE	CIF	400kbps	PSNR(Luma)	32.13	32.05	32.08
			Speed up	1	**3.8**	2
SEAN	CIF	240kbps	PSNR(Luma)	38.16	37.82	38.02
			Speed up	1	**13.9**	2
AKIYO	CIF	180kbps	PSNR(Luma)	40.41	40.1	40.3
			Speed up	1	**12.1**	2
STEFAN	CIF	900kbps	PSNR(Luma)	26.76	26.61	26.69
			Speed up	1	**2.21**	2

Table 2 Simulation Result of FQPS, 2SS and proposed SQIA



Sequence	Format	Bit-Rate	Frame Level	Block Level	Point Level
NEWS	CIF	300kbps	5%	60%	4.24
WEATHER	CIF	300kbps	14%	80%	3
FOREMAN	CIF	450kbps	0%	11%	4.32
TABLE	CIF	400kbps	4%	51%	4.48
SEAN	CIF	240kbps	14%	78%	3.04
AKIYO	CIF	180kbps	11%	79%	3.55
STEFAN	CIF	900kbps	0%	15%	4.32

Table 3 Statistics for each Level of SQIA

7. ACKNOWLEDGEMENT

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