A Modified TZ Search Algorithm for Parallel Integer Motion Estimation in High Efficiency Video Coding

Doan Trung Nghia, Tae Sung Kim, Hyuk-Jae Lee, and Soo-Ik Chae
Inter-university Semiconductor Research Center Department of EECS, Seoul National University
Seoul, Korea
nghiadt@capp.snu.ac.kr, tskim@capp.snu.ac.kr, hyuk_jae_lee@capp.snu.ac.kr, chae@sdgroup.snu.ac.kr

Abstract—**This paper proposes a new integer motion estimation algorithm which is designed for hardware execution by modifying the conventional TZ search to allow parallel motion estimation of all PU partitions. The algorithm consists of three phases, the first, raster, and refinement searches. At beginning of each phase, the algorithm obtains the search points required by the original TZ search for all PU partitions in a CU. Then, all the search points are used for the estimation of the motion costs for all PUs and the best search points are selected for all PUs. Compare to the conventional TZ search algorithm, the proposed algorithm decreases BD-BR by 1.06%.**

Keywords-component; High Efficiency Video Coding (HEVC); Integer Motion Estimation (IME), TZ Search Algorithm

I. INTRODUCTION

Integer Motion Estimation (IME) [2] is one of the core computations in video compression and extensive research has been made to reduce the complexity of IME [3]. The TZ search algorithm is a widely-used algorithm and it is adopted in the reference software of the High Efficiency Video Coding (HEVC) standard [1]. Although the TZ search algorithm is very efficient to obtain accurate motion vector with reasonable complexity, it is designed for software implementation, not for hardware implementation. The TZ search algorithm performs motion estimation for PUs sequentially with each PU tracking its own search points. Therefore, different PUs track different search points for motion estimation. Aiming at hardware execution, this paper proposes a new IME search algorithm that modifies the TZ search algorithm to make multiple PUs estimate the motion cost in a parallel manner without a degradation of the compression efficiency. To this end, the proposed algorithm obtain the search points for all PUs prior to the execution of the motion estimation for any PU. Then, the motion estimation is performed for all PUs in a CU for all the obtained search points. This order of operations is suitable for hardware execution which can perform the motion estimation of multiple PUs in a parallel manner. The proposed search algorithm increases the number of search positions for individual PUs although the total number of search points for all PUs are the same. This increase of search points may slow down the execution of the algorithm in software but may not affect the speed of hardware execution if the hardware is designed to perform multiple PUs in parallel. Furthermore, the increased number of search points for individual PUs give a chance to obtain the better integer motion vector compare to the original algorithm. Experimental results show that the proposed algorithm achieves 1.06% better BD-BR when compared with the original TZ search algorithm. The rest of this paper is organized as follows. The proposed algorithm is explained in Section II while Sections III and IV present the experimental results and conclusions, respectively.

II. PROPOSED CONCURRENT TZ SEARCH ALGORITHM

Fig. 1 illustrates the proposed algorithm which consists of three main phases: the first search, raster search, and refinement search phases. In the first search phase, the search points required by Diamond search are determined for individual PUs. This determination of search points are made for all PUs prior to the execution of motion estimation by any PU. Then, the cost of motion vector is estimated for all the search points by all PUs. The proposed algorithm does not allow early termination in Diamond search so that all possible search points are examined. After Diamond search, the best positions are updated for all PUs and the distance to the initial search centers are obtained. If this distance is equal to one for any PU, 2-point search [1] is to be performed. Prior to the execution of 2-point search for any PU, the demand for 2-point search is tested for all PUs. If more than one PU requires 2-point search, then all the search points for the required PUs are determined. For these search points, the motion cost is estimated for all PUs and the best point is obtained for all PUs.

The second search phase is modified from the raster search of the TZ search algorithm for concurrent execution. As a result of the first search, some PUs need to perform the raster scan if the distance between its current best position and its search center is larger than the predetermined parameter iRaster [1]. Similar to the first search, the search points are obtained for all PUs that require the raster search prior to the execution of the raster search for any PU. After all search points are determined, the motion cost is estimated for all the search points for all PUs. The third phase is modified from the refinement search in the TZ search algorithm. Similar to the original TZ search, Diamond search and 2-point search are repeated until the termination condition is satisfied. For each step, the search points are obtained for all PUs prior to the execution of the motion estimation for any PU. Then, motion estimation is performed for all PUs. The termination condition is modified such that the best distances of all PU partitions are equal to 0. Note that this condition is much tighter than the one used by the original TZ search algorithm which determines the termination for each PU partition independently. In the proposed refinement phase, a PU partition which already contains its termination condition in the previous iterations can be updated with the new best position during the search operation of other PUs. If the distance of the newly updated position is larger than 0, this PU partition needs to be refined until there is no better position found for this PU.

In an HEVC encoder, the final motion vector of a PU is used as one of the AMVP candidates of another PU in the same CU. Therefore, there exists dependence between the motion estimations of two PUs in a CU. This dependence does not allow concurrent execution of multiple PUs in a CU, and as a result, it prohibits the proposed concurrent TZ search algorithm. To eliminate this dependence, the unavailable AMVP candidate of the second PU is replaced by an AMVP candidate of the first PU partition. This replacement might give imprecise values for the unavailable AMVP candidates; nevertheless, all PUs can be predicted at the same time since there is no dependences between them.

III. Experimental Results

The RD performance of the proposed IME algorithm is given in Table I. The BD-BR is estimated with six test sequences. On average, the BD-BRs are decreased by 0.99%, 1.13%, and 1.39% for Y, U, and V components, respectively. Combining the three BD-BRs, the weighted BD-BR is 1.06% which is obtained as (1). The number of the search points required by the proposed algorithm is given in Table II. The second row shows the number of the search points required by the original TZ search algorithm. In the proposed algorithm, the motion cost is estimated at all of these search points for all PUs. Among these search points, many of them are shared by different PUs. For example, two different PUs have the same AMVP, then their initial search points in the first search should be same. Even in the case when two PUs have different AMVPs, they may share some initial search points if the two AMVPs are close to each other. For these shared search points, the proposed algorithm does not have to be executed twice. Therefore, the number of search points is much less than the original number of search points. The third row of Table II shows the number of search points for the proposed algorithm and the fourth row shows the ratio between the second and third rows as described in the table. All the numbers in this table represent the average over six test sequences as in Table I. The removal of the early termination for Diamond search in the proposed algorithm increases the number of search points in the first search and refinement search. On average, the number of search points in the proposed IME is about 52% of the original number of search points.

$$Weighted\ BD\_BR = \frac{6 \times BD\_BR(Y) + BD\_BR(U) + BD\_BR(V)}{8} \quad (1)$$

TABLE I. RD PERFORMANCE OF THE PROPOSED IME ALGORITHM

Sequence C	**BD-BR**		
	Y	U	V
Keiba	-1.38%	-2.23%	-3.15%
BQMall	-0.77%	-1.30%	-1.14%
BasketballDrill	-0.72%	-0.15%	-1.23%
Flowervase	-1.64%	-1.34%	-0.14%
PartyScene	-0.53%	-0.27%	-0.79%
RaceHorses	-0.90%	-1.48%	-1.87%
Average	**-0.99%**	**-1.13%**	**-1.39%**

TABLE II. THE NUMBER OF SEARCH POINTS

Sequence C	**The First Search**	**Raster Search**	**Refinement Search**	**Ave. Search Pos. in a CU**
TZ Search (A)	232.59	2803.57	480.44	1005.68
Proposed algorithm (B)	103.7	996.73	284.32	480.42
Ratio ((1-B/A)×100)	55.42	64.45	40.83	52.23

IV. Conclusions

This paper aims to propose an efficient IME search algorithm for hardware implementation. The TZ search algorithm is modified such that all PUs can be processed in a parallel manner, and consequently, the operation is suitable for hardware implementation. The modification increases the complexity of the algorithm if it runs in software but allows a fast execution in hardware. For future research, the algorithm is to be implemented in hardware and its efficiency is to be compared with previous hardware implementations for IME.

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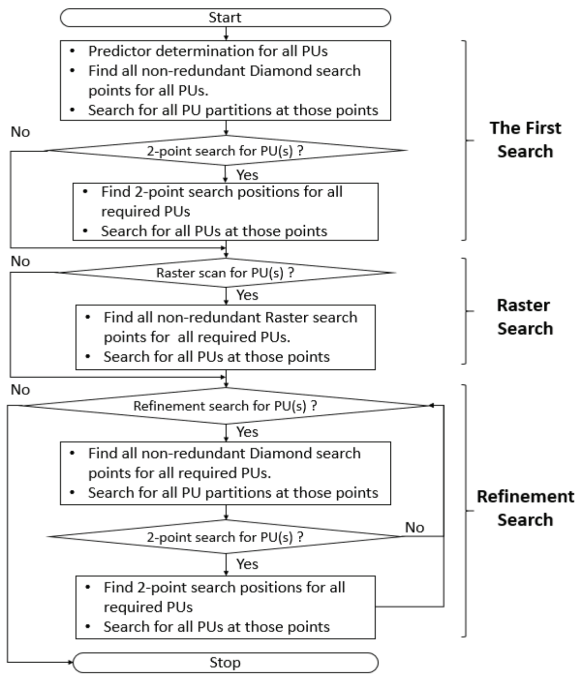

Fig. 1. Flowchart of the proposed IME algorithm