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AN EFFICIENT FAST HEVC ENCODING TECHNIQUE

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ABSTRACT

HEVC video coding standard uses a structure of flexible Coding Unit (CU) quad tree. This flexibility increases the coding efficiency and allows the standard to achieve better rate-distortion performance compared to its prior H.264/MPEG-4 AVC. The improvement of coding efficiency came at the cost of high encoding complexity. This paper presents a fast algorithm to reduce the encoding complexity by an early termination decision with reference frame selection. Experimental results for seven standard video sequences show that the proposed algorithm can save up to 53.79% of the encoding time compared to the original HM14. Different video sequences with different frame rates, quantization parameters and resolutions were used in the experiments. The paper also presented the effect of changing resolutions, frame rates and bit rates on compression efficiency for both HM and the proposed algorithm. In comparison with the original software, the proposed algorithm presents significant improvement and time saving. In addition, the proposed algorithm outperformed two of the best state of the art proposed methods.

Keywords: *Coding Unit, HEVC, Encoding Complexity, Rate Distortion, Early Termination.*

1. INTRODUCTION

HEVC is a new compression standard with higher compression efficiency. It has been designed as a replacement of the prior standard Advanced Video Coding (H.264/AVC). HEVC achieves better compression performance compared to other compression standards but with a much higher encoding complexity. Many coding tools have been added to the new HEVC that led to this capability of bitrate reduction. The adopting of broad and flexible Coding Unit (CU) is one important and effective tool in HEVC. The CU quad tree decision is a high computational process as the encoder has to make numerous number of computations to determine the best Prediction Unit (PU).

A frame slice in HEVC may contain Large Coding Unit (LCU) where each LCU can be divided into four CUs. The partitioned CU can be further divided into smaller CUs. The process of CU dividing is recursively conducted until reaching the smallest CU. In addition, encoder processes a set of computations to define the best PU to encode a CU with its associated Transform Unit (TU). To encode a LCU the encoder goes through number of options that depend on the depth of the quad tree.

Compared to the prior H.264/AVC video coding, HEVC has improved the macroblocks sizes to 64×64 compared to 16×16 in H.264. This extended macroblock size provided an HD compression capability for the new HEVC. The high flexible coding structure and adopting of adaptive loop filter also new features in HEVC [1]. The performance of reconstructing images with better quality and better subjective and objective performance explains the advantages of HEVC standard. In the contrary, the present version of the HEVC standard suffers from high latency and computational complexity. The HEVC encoder was formally released as an international standard in 2013. HEVC has been determined as a codec that serves high definition video sequences [2].

The HEVC overview is presented in Section 2. The literature survey of the recent proposed improvements on HEVC is discussed in Section 3. Section 4 and Section 5 showed the proposed algorithm and the experimental results respectively. Section 6 concluded the paper.

2. HEVC OVERVIEW

The encoding process in HEVC contains three main divisions; the coding unit (CU) which

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represents the root of the quadtree which is for mode prediction such as INTER and INTRA prediction, the prediction unit (PU) for coding the mode in addition to motion estimation and rate distortion, and the transform unit (TU) for transform and entropy coding. In HEVC a frame is divided into large coding units (LCU), each LCU has a structure of 64×64 pixels. This LCU can be further divided into four 32×32 pixels. Each LCU can be recursively divided into smaller CUs. The 8×8 pixels size is the smallest possible CU. There is a combination of CU structures that can be vary from the LCU to the smallest CU. The rate distortion (RD) is calculated for each CU and the one with the minimum RD is chosen as the best unit. The HEVC way of representing these variable block sizes is considered efficient as blocks in different regions can be coded and give fewer bits. Unfortunately, this combination led to a higher computational complexity compared to the H.264/AVC.

The HM code supports in default four CUs with the corresponding depth of coding as 0, 1, 2, 3. For the PU, the sizes are from 64×64 to 4×4. In inter-mode prediction, the frame is divided from LCU which is non-overlapping units. The process of LCU division is recursively ran until reach the maximum coding depth. For each of these divided units, the RD cost is calculated to determine the PU and decide better unit [3].

At depth two, four CUs will be extracted where each unit is tested for the skip mode. The unit that does not pass the test, it is further divided into four smaller CUs in a recursive call. The splitting is continue to the fourth level where the minimum 8×8 pixels unit is reached. The coding considers the quadtree leaves up to the root of the tree. The best depth and the optimal prediction mode is chosen after the cost calculation using the Lagrangian equation to find the minimum cost between all child nodes and the parent.

3. LITERATURE SURVEY

Since the HEVC standard is released in 2013, many researches and ideas have been proposed to improve the high computational complexity in the standard. Two proposed algorithms have reduced the computational complexity and recorded in the HEVC test model (HM). These two proposed algorithms have been adopted in the HEVC and used as optional configurations in term of HEVC speeding up [4, 5]. The proposed idea in [4] is adopted as an early SKIP detection setting. The main function is to decide whether an early termination should be taken or not. In [5], a fast mode setting is designed to judge whether PUs in current depth should be checked or not.

In [6], a speedup of about 60% has gained with 0.86% bitrate increase. The idea exploited the information from already coded blocks for previous part modes. This information helps to terminate any successive sub blocks processing. In [7], an algorithm of inter mode decision is proposed to speed up the encoding process. The idea exploits the texture of CUs to provide a CU partitioning model using Sobel operator. This operator produces the edges that used mainly in the partitioning process. The proposed algorithm obtained 45.3% speeding up with 1.23% bitrate increase.

In [8], the temporal correlations of adjacent frames' co-located CUs were exploited to propose a fast inter mode decision algorithm. By considering these correlations the algorithm reduced the computations needed in HEVC. The algorithm gained 33% - 43.3% reduction on the encoding time with 0.4% bitrate increase. In [9], an inter-mode decision technique was proposed based on the correlation between PU modes. The proposed algorithm was merged with an early skip algorithm to speedup the encoder more. The result showed that the combined ideas gained 39.1% time reduction in encoding time with negligible quality loss. The correlation between the LCU's depth and redundancy of spatial and temporal content is an important factor. In [10], this correlation was studied and exploited. Based on these results, the best mode of the current block was chosen. The experiments of this algorithm showed 50% reduction in the encoding time with 0.4% bitrate increase. In [11], the correlation of the depth of neighboring CUs and the current CU depth was taken as an important factor especially in high frame rate sequences. A fast coding decision based on the unit depth is proposed and tested. The proposed algorithm

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yielded a 25% speedup at 0.16% increase in bitrate compared to the HM8.

In [12], an algorithm based on machine learning technique was proposed. The algorithm used to conduct inter mode selection process instead of the full exhaustive searching technique. The proposed algorithm achieved 44.7% speedup with 1.35% loss in the coding efficiency. In [13], an idea of early CU termination was proposed. The proposed algorithm used the average rate-distortion cost of the skipped CUs and the spatial correlation of the CUs that are neighboring current CU. Around 45% speedup with 1.35% bitrate increase are the result of implementing this proposed algorithm. In [14], a method was proposed and evaluated compared to HM9.0 using low delay configuration. The main proposed idea based on optical flow of frames that have been down sampled to optimize inter prediction. The results showed 43-62% speedup with 0.06 dB loss in the quality.

In [15], under the low delay P-Main configuration of HM9.0 the proposed algorithm was evaluated. The idea proposed a fast mode selection using Markov random field. The implementation of the algorithm presented 53% speeding up with 1.32% increase in bit rate. In [16], an algorithm was proposed based on the rate distortion cost of parent CU and the current depth. The authors devised the idea for fast inter mode decision. The algorithm offered 38% speed up with less than 1.7% loss in quality. In [17], an algorithm was proposed for an early CU size-determination. The adaptive depth-range determination and early determination of unnecessary motion in CU sizes are exploited in the idea to speedup the total encoding time of the HEVC.

As discussed in this section, some of the previous works on HEVC improvement gave high encoding speedup; however, it showed high loss in compression quality, rate distortion performance or bit rate increasing. Other works showed unsteadiness in compression performance for different frame resolutions and frame rates. On the other hand, the proposed algorithm presented high encoding speedup with negligible loss of quality. In addition, the proposed algorithm was tested and evaluated for different resolutions and frame rates and showed high and steady performance.

4. PROPOSED ALGORITHM

As have been discussed in the previous sections, it is clear that the HEVC reference still needs more improvement especially on speeding up the encoding process. One idea to reduce the encoding computational time can be achieved by improving mode decision and other tools exist in the reference software. The estimation of CU depth is also another possible idea to reduce CU quad tree complexity. In the inter mode prediction, all inter blocks must be checked before deciding the best mode. However, the best mode is possible to be an intra block and all tests of the inter prediction blocks are redundant and time consuming. In inter prediction, an LCU could provide better PU than smaller CUs. In this case, it may be time consuming to go in further tree depth while the most candidate is in depth one or depth two.

The main idea that the proposed idea used is to test blocks with specific conditions to decide whether it will be a candidate block or not. The conditions are determined to study the likelihood of the blocks and terminates the process when it is expected to be less possible candidate. If the proposed test was successful to achieve this likelihood determination, it will avoid the encoder to go through all the consuming computations to check all blocks which then achieves higher performance improvement.

The reference frames are another important factor that affect the performance of the HEVC reference software. Searching five references in average is a high computational process. The fact that the nearest reference frame is the most candidate frame to contain the best block can be exploited with the idea of blocks determination then a fast prediction technique can be devised.

In this paper, a recursive splitting with early termination decision based on the CU levels is proposed. Based on the basic fact of the similarity between neighbor blocks in temporal and spatial content of a video sequence, the CU fast decision is designed to exploit this fact by checking these spatial neighbors and co-located temporal to predict the candidate CU depth. On

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the other hand, the nearest reference frame has the highest likelihood to contain the candidate CU. This possibility is decreased by checking farther reference frames. The study of likelihood of candidate CU sizes with reference frames is shown in Table 1. Five HD sequences (1920×1080) were tested to evaluate the likelihood of choosing a reference frame and the CU size in each reference frame. The results show that nearest reference frame is the most likely one to be chosen since it had the highest likelihood values. Moreover, LCUs are the most likely CUs that will provide the best match for a given block. The likelihood was tested for four QP values: 22, 26, 32, 36. The average results of the four QPs are calculated and shown in Table 1.

Table 1 CU And Reference Frames Selection Likelihood

Sequence name	Reference 0	Reference 1	Reference 2	Reference 3	Reference 4	LCU
ParkScene	72.6	13.2	7.3	4.5	2.4	88.4
Cactus	74.5	12.9	7.1	3.2	2.3	81.7
BasketballDrive	78.2	11.9	5.3	3.2	1.4	82.3
BQTerrace	82.3	9.8	4.6	2.1	1.2	89.5
Kimono	79.5	13.1	3.2	2.7	1.5	79.1

According to the results gained in Table 1, we exploited these two observations to reduce the number of CUs and reference frames that need to be checked. The proposed algorithm executes testing blocks with sizes 64, 32 and 16 at the first stage. For the first reference frame (Reference 0), if the largest block size meets the termination conditions, an early termination is implemented and block with best RD is chosen. If the conditions are not met, the splitting continues and RD of smaller blocks are tested. The two conditions are: smaller neighbor blocks 32 and 16 give worst RD or the smaller blocks in the first reference frame give worst RD. After implementing these two conditions for the first reference frame, the best block with early termination is chosen. The next step of the proposed algorithm is to check next reference frame (reference 1) for the selected block size. The next reference frame is checked for only the chosen block size. If the RD is worse than the results for the first reference frame (reference 0), another early termination is applied as farther references are less likely to contain the better match according to results in Table 1.

The proposed algorithm gives an option to early termination of the encoding process. The encoder does not need to build a full search tree. Short tree means less small block sizes to be checked and then less computational complexity.

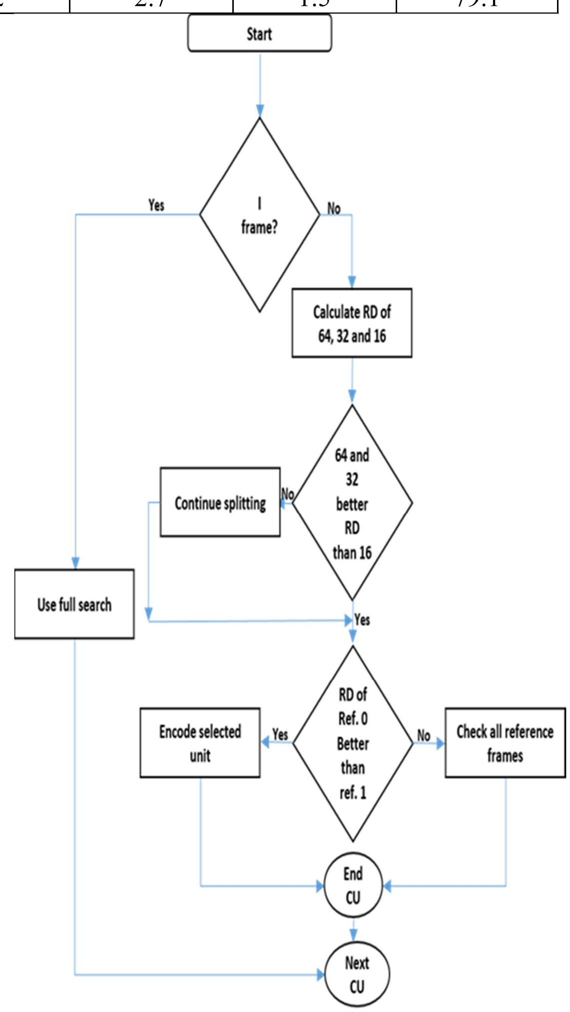

Figure 1 Entire Proposed Algorithm Flowchart

The flowchart of the entire proposed algorithm is shown in Figure 1.

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The proposed algorithm proceeds as in the following outline.

1. If the frame is an I frame, use the full intra search. Then go to step 6.
2. Compute RD of 64, 32 and 16 for reference 0.
3. If RD of 64 and 32 are better than 16, go to step 4, Otherwise continue splitting CUs.
4. Compute the RD of the candidates for reference 1. If RD of reference 0 is lower than reference 1, choose the CU with lower RD as best candidate and go to step 6. Otherwise, continue checking all reference frames.
5. Among all candidates that were checked, select the candidate that provides the smallest RD cost.
6. Check the next CU if needed.

5. EXPERIMENTAL RESULTS

Experiments of the proposed algorithm select the reference software HM14.0 as test model to verify the performance gained. Two state-in-the-art algorithms [7, 16] were selected to compare the proposed algorithm with. The experiments used configurations of lowdelay_P main. As HEVC is initially devised for high definition videos, seven video sequences with HD resolutions (1920×1080), (1280×720) and (832×480) were selected for the testing. First 100 frames of each sequence were tested. The full experiment configurations are given in Table 2.

Table 2 Experiments Configurations

MaxCUsize	64×64
MaxCUdepth	4
Max reference frames	5
Group of pictures	1
Search range	64
Search mode	EPZS pattern
QP values	22, 26, 32 and 36
Sequence type	IPPP

These parameters and the tested video sequences have been chosen to be similar to those parameters in [7, 16] to get more comparison fairness. The experiments were conducted on a machine with Intel core-i7 CPU and 4-GB RAM. At the first stage, the proposed algorithm has been evaluated compared to the HM14.0 reference software. In the second stage, same experiments have been conducted after implementing algorithms in [7, 16] using same parameters to create fair comparable results. These two algorithms were implemented as it were described in the published papers. The results were recorded for full comparative study that has been run in this paper. The comparison study shows the proposed algorithm performance and [7, 16] results in Table 3. As shown in the table, three different frame resolutions were selected to give a wider evaluation study. In addition, four different QP values were selected and tested (22, 26, 32 and 36). Tested sequences were 30 fps and 25fps. Table 3 shows the average results of the four QP values.

To evaluate the performance of the proposed algorithm compared to the reference HM 14.0 and two state-in-the-art papers, the metrics of the Bjontegaard were used. These metrics are the peak signal-to-noise ratio (BD-PSNR), the Bjontegaard delta bit rate (BD-BR), and the percentage of encoding time change (ΔTS) [18]. The performance of the proposed algorithm compared to HM 14.0 is shown in Table 3. The proposed algorithm shows on average 53.79% saving of the encoding time. Our algorithm was always faster than [7, 16]. It also shows reliable performance for all tested resolutions and frame rates. However, [7] showed less performance for smaller video resolutions. The proposed speedup technique achieved high performance on encoding time reduction with no major penalty in either bitrate or PSNR. The importance of the proposed algorithm is shown clearly in the experimental results. The algorithm offers high encoding speedup with negligible loss of PSNR and slight increase of bit rate. However, the algorithm does not suggest an intra speedup technique.

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Table 3 Performance Of The Proposed Algorithm Compared To HEVC 14.0 And [7, 16]

Sequence	Proposed		[7]		[16]	
	ΔBD-BR (%)	ΔTS (%)	ΔBD-BR (%)	ΔTS (%)	ΔBD-BR (%)	ΔTS (%)
Party Scene (1920×1080)	2.3	-54.12	1.5	-53.61	2.31	-41.17
Cactus (1920×1080)	1.78	-52.01	1.53	-50.43	1.86	-43.94
BQ Terrace (1920×1080)	1.05	-50.13	0.97	-49.79	1.68	-36.85
Johnny (1280×720)	0.92	-67.92	0.78	-67.14	1.08	-34.06
Kristin and Sara (1280×720)	1.68	-61.45	1.02	-58.72	2.13	-33.26
Race Horses (832×480)	2.31	-46.19	1.64	-37.11	3.21	-26.19
Party Scene (832×480)	2.16	-44.71	1.45	-35.07	2.61	-31.47
Average	1.74	-53.79	1.27	-50.26	2.12	-35.27

6. CONCLUSIONS

In this paper, we presented an efficient HEVC encoding complexity reduction technique. The proposed algorithm reduced the CU possibilities and the number of reference frames to be checked. The algorithm saves time efficiently in different high definition video resolutions with different frame rates. Experimental results also showed that our algorithm offered confidence improvement for different QP values. In addition, results showed that the proposed algorithm can save up to 67.92% of the encoding time compared to the HM14.0 and 53.79% on average for different video resolutions, frame rates and QPs. As future work, the proposed algorithm can be combined with a fast intra encoding technique to get higher time saving.

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