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ALGORITHMS FOR FAST IMPLEMENTATION OF HIGH EFFICIENCY VIDEO CODING

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2017

I dedicate this work to God Almighty for His grace and mercies extended to me which enabled me to complete this study.

ACKNOWLEDGEMENT

I want to thank God Almighty, the most merciful and the most loving, from the depth of my heart for the inspiration He shower on me which enable me to make some humble contributions in this complex field of study. My special gratitude goes to my main supervisor, Dr. Zaid Omar, who accepted me when it mattered most, polished me and set me up in the right direction. His thoroughness in cross checking my work with so much love and consideration is a virtue I am trying to learn.

From the depth of my heart I thank my co-supervisor, Dr. Ab Al-Hadi Ab Rahman for the specialist insights and directions he brought forward into this study from the inception of this work. At the point when journal reviewers almost discouraged me, he saw the rays of light at the end of the tunnel and brought forward courage and directions on how to respond to their comments. His directions were full of insight and the yielded wonderful results.

I also want to thank specially As. Prof. Muhammad Mun'im Ahmad Zabidi who played a critical role at the inception of this study, He was able to see and to acknowledge the research value of this study.

I also want to thank my wife, Mrs. Joyce Ifeoma Jaja for supporting me diverse ways during this study. The sacrifices she made especially in enduring my absence during this study is wonderful; it is only God that would bless and reward you in full.

My appreciation and gratitude also go to my children, Miss Gift Edward Jaja and Miss Mather Edward Jaja, for all the sacrifices they made during this study, especially for enduring my absence.

I also thank all brethren that held me in their prayers in course of this study.

May the blessings of God be in abundance in your lives.

ABSTRACT

Recently, there is higher demand for video content in multimedia communication, which leads to increased requirements for storage and bandwidth posed to internet service providers. Due to this, it became necessary for the telecommunication standardization sector of the International Telecommunication Union (ITU-T) to launch a new video compression standard that would address the twin challenges of lowering both digital file sizes in storage media and transmission bandwidths in networks. The High Efficiency Video Compression (HEVC) also known as H.265 standard was launched in November 2013 to address these challenges. This new standard was able to cut down, by 50%, on existing media file sizes and bandwidths but its computational complexity leads to about 400% delay in HEVC video encoding. This study proposes a solution to the above problem based on three key areas of the HEVC. Firstly, two fast motion estimation algorithms are proposed based on triangle and pentagon structures to implement motion estimation and compensation in a shorter time. Secondly, an enhanced and optimized inter-prediction mode selection is proposed. Thirdly, an enhanced intra-prediction mode scheme with reduced latency is suggested. Based on the test model of the HEVC reference software, each individual algorithm manages to reduce the encoding time across all video classes by an average of 20-30%, with a best reduction of 70%, at a negligible loss in coding efficiency and video quality degradation. In practice, these algorithms would be able to enhance the performance of the HEVC compression standard, and enable higher resolution and higher frame rate video encoding as compared to the state-of-the-art technique.

ABSTRAK

Kebelakangan ini, terdapat permintaan yang tinggi terhadap kandungan video dalam komunikasi multimedia. Ini membawa kepada peningkatan keperluan bagi penyimpanan dan pengurusan jalur lebar oleh pembekal perkhidmatan internet. Justeru, menjadi satu keperluan bagi sektor piawaian telekomunikasi Kesatuan Telekomunikasi Antarabangsa (ITU-T) untuk melancarkan piawaian pemampatan video baru yang akan menangani cabaran bagi mengurangkan saiz fail digital dalam media storan dan jalur lebar penghantaran di rangkaian. Piawaian mampatan video bercekapan tinggi (H.265 / HEVC) telah dilancarkan pada bulan November 2013 bagi menangani cabaran ini. Piawaian baru ini dapat mengurangkan sebanyak 50% saiz dan lebar jalur fail media yang sedia ada, tetapi lengah komputeran menambah kira-kira 400% dalam pengekodan video HEVC. Kajian ini mencadangkan satu penyelesaian kepada masalah di atas berdasarkan kepada tiga bidang utama HEVC. Pertama, dua algoritma anggaran gerakan yang cepat berdasarkan struktur segitiga dan pentagon dicadangkan untuk mempercepatkan anggaran dan pampasan gerakan. Kedua, skim pemilihan mod antara-ramalan yang dipertingkatkan dan yang lebih optimum dicadangkan. Ketiga, peningkatan skim mod sesama-ramalan dengan lengah yang lebih rendah dicadangkan. Berdasarkan model ujian perisian rujukan HEVC, setiap algoritma dapat mengurangkan masa mengekod merentasi semua kelas video secara puratanya sebanyak 20–30%, dengan pengurangan terbaik 70% beserta kehilangan kecil dalam kecekapan pengekodan dan pengurangan kualiti video yang boleh diabaikan. Secara keseluruhannya algoritma ini akan meningkatkan prestasi piawaian pemampatan HEVC, serta membolehkan resolusi yang lebih tinggi dan pengekodan video pada kadar kerangka yang lebih tinggi berbanding dengan teknik sedia ada yang tercanggih.

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LIST OF ABBREVIATIONS

AMP	–	Asymmetric motion partitions
CBF	–	Coded block flag
CIF	–	Common intermediate format-352x288 pixels
CPU	–	Central processing unit
CTB	–	Codint tree block
CTU	–	Coding tree unit
CU	–	Coding unit
ECU	–	Early coding unit
EMD	–	Enhanced mode decision algorithm for HEVC
ESD	–	Early skip decision
FRS	–	First row substitution
FSRS	–	First second row substitution
HEVC	–	High Efficiency Video Coding
ITU	–	International Telecommunication Union
ITU-T	–	International Telecoomunication Union-Telecommunication standardization sector
JCT-VC	–	Joint Collaborative Team on Video Coding
LCU	–	Largest coding unit-64x64 pixels
MPEG	–	Motion Picture Experts Group
PSNR	–	Peak signal to noise ratio
PU	–	Prediction unit
QCIF	–	Quarter common intermediate format-176x144 pixels
RD	–	Rate distortion
RDO	–	Rate distortion optimization
SAD	–	Sum of absolute difference
SATD	–	Sum of absolute transformed difference
TU	–	Transform unit
TZSearch	–	Test zone search

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CHAPTER 1

INTRODUCTION

When multimedia incorporated pictures or video contents in the early 90s, the major challenge then was how to represent all the data from these contents in an efficient manner. Since these visual contents consist of three channels - red, green and blue channels - it then means that the data from these pictures or video would be difficult to store or transmit in its raw form without it overwhelming the transmission media [1, 2]. It became necessary to compress the data to fit into storage devices and transmission channels. The need to compress picture or video data has made it necessary to define a standard, as well as specify its syntax and semantics [3, 4, 5, 6, 7]. The standard ensured that any picture compressed or coded through it can be displayed by any decoder that conforms to the syntax and semantics of the standard.

The first video compression standard defined was the H.120 in 1984 by the International Telecommunication Union (ITU) [8]. The application of this standard was in the area of video conferencing and it transmitted National Television System Committee (NTSC) or Phase Alternating Line (PAL) data over communication media. The video display was the 625 lines, 50 fields or frames per-second or 525 lines, 60 fields or frames per-second at a bandwidth of 2048 kbits/s or 1544 kbits/s; the audio quality associated with it was speech [9]. This standard, which is now outdated, was later revised in March 1993 to improve its specifications. In 1990, the H.261 standard was launched by the ITU Telecommunication Standardization Sector (ITU-T). The target of this standard is to achieve transmission of multichannel data at 64 kbit/s over integrated services digital networks (ISDN); the base version of the standard had a resolution of 176 × 144 pixels. This standard was later revised in May 1994 to accommodate a higher frame size measuring 352 × 288 pixels. In November 1992, the Motion Picture Expert Group (MPEG) launched the first standard for entertainment called MPEG-1. This standard targeted digital entertainment, storage and media transport in its application. The typical frame size of this standard was 352 × 240 pixels. The bitrates of this standard supported up to 1.5 Mbps (mega bits per seconds) and the corresponding audio quality was stereo sound [10]. Following that, the next compression standard was the MPEG-2/H.262 jointly launched by MPEG and the ITU-T; it was released to the public in November 1994. This standard targeted multimedia broadcasting, digital video storage in disc and high definition television broadcast. The frame size of this standard is 720 × 480 pixels with bitrates of 4–6 Mbps and surround sound quality. In May 1996, the ITU-T launched the H.263 compression standard which was later revised in January 1998. This standard defined the syntax and semantics of wireless communications and video conferencing. The frame sizes were 176 × 144 pixels and 352 × 288 pixels for version 1 and 2 respectively; the bitrates were in the range 20–384 kbps. MPEG subsequently launched another compression standard called MPEG-4 in January 1999 which was then revised in January 2000. The applications targeted by this standard were web authoring, multimedia compression and wireless video phone. The supported frame sizes were 176 × 144 pixels, 352 × 288 pixels and 720 × 480 pixels; the bitrates range is 20 kbps–6 Mbps. The audio quality was speech, music, stereo and surround sound.

The compression standard being phased out currently is the H.264/AVC (advanced video coding standard) which was defined in May 2003 by the Joint Collaborative Team on Video Coding (JCT-VC) constituted by the ITU-T and the MPEG [11]. This standard pushed the frontier of video coding to an advanced level which defined the rich multimedia communications being enjoyed today. The target of this standard was cellular communications, multimedia broadcasting, security surveillance and personal media devices such as camcorders. This standard was designed for higher frame resolutions up to 4k. Because of the success of this standard, demand for devices with higher resolution increased; this scenario posed a fresh challenge over multimedia bandwidth and storage.

Due to the increasing demand for higher video resolutions in multimedia wireless communications cited above and the high storage space required by these service providers, it became necessary to define a new video compression standard, besides the state-of-the-art H.264/AVC, that would be able to cut down digital video file sizes in storage devices, reduce file transfer rates during digital transmission and to offer higher resolutions up to 8k. To address these challenges, the international Telecommunication Union (ITU-T) and the moving Picture Experts Group (MPEG) jointly developed and published, in April 2013, the first edition of the high efficiency video coding standard (H.265/HEVC) to eventually replace the state-of-the-art H.264/AVC standard [12].

The HEVC video compression standard is based on a similar set of coding tools as the H.264/AVC. The major difference is that the largest coding unit (LCU) in the HEVC is 64x64 pixels while the largest coding unit-called the macroblock in H.264/AVC is 16 × 16 pixels. Because of the relatively larger coding blocks in HEVC, the standard can support higher resolutions up to 8192 × 4320 pixels - ultra-high definition, also called the 8k [6]. In the first version of HEVC standardization, three profiles were named: *main, main 10 and main still picture*. A profile is a definition of a set of tools necessary to encode videos in a certain mode to produce unique bits streams for that particular profile. HEVC is designed to encode videos at a very high compression ratio compared to all other existing standards; this means that the HEVC encoder optimizes the bits budget required to encode each frame and the entire video sequence. HEVC when compared to the performance of the H.264/AVC increases video compression to about 50% at a better visual quality [13]; but in a complexity test conducted by Ericsson reported in [14], it was discovered that HEVC is 50-100% computationally more complex in decoding and 400% more complex in video encoding.

This high computational complexity of HEVC is due to the complex designs and the tool sets of HEVC in all profiles [15, 16]. With such high computational complexities, the coding delay in terms of the encoding time is too high such that real time encoding of video files using this standard poses a major challenge at present for the full deployment of the HEVC. For example, a mere four seconds raw video from the 'Bus' sequence dataset consisting of 100 frames with a resolution of 352 × 288 pixels takes 30 minutes to encode in this standard using Intel Core i7-4700HQ CPU clocked at 2.4GHz; but the encoded version plays back for only 4 seconds. This latency in encoding can be extrapolated to determine the time it takes to encode an ultra-high definition (UHD) video that consist of 180,000 frames–which could take at least a day.

The delay in encoding that is observed in this standard is due, mostly, to complex encoding tools such as inter-prediction mode decision, intra-prediction mode decision and complex motion estimation algorithms built into the standard to enhance coding efficiency and the quality of the encoded video [17]. This study looked at three key areas that induce high latency to the encoding process with a view to trade off some minimal quality of the encoded video to reduce the computational complexities associated with video compression in this standard. This could possibly cut down on the encoder delay. These key areas of the standard optimized in this study are: the motion estimation algorithms, the inter-prediction mode decision and the intra-prediction mode decision. An algorithm was devised in each of these areas that may significantly reduce latency or delay in encoding. Cumulatively, these algorithms are able to yield higher efficiency in encoder timing while maintaining acceptable video quality.

1.1 Problem Statement

As a result of the successful deployment and service of the H.264 which pushed video resolution up to the 4K, the demand for higher resolutions leading up to the 8K arises. These higher resolutions and the accompanying data could potentially cause a spill over the limits of data networks. To resolve this meltdown ahead of time, the ITU-T and the MPEG jointly drafted the next generation video coding standard, the HEVC, to address these limitations. Since standardization takes place once every 10 years, the designers of the standard built-in coding tools that would ensure hitch free service delivery within the projected period and still maintain the target objectives. Subsequently however, at the stage of testing and validation of the standard it was discovered that computational complexities were the next challenge to overcome in deploying the HEVC. Computational complexities mean that the standard entails an overload of arithmetic operations that leads to unnecessary delay in the codec.

The purpose of this study is to propose algorithms to reduce computational complexities in the newly defined HEVC standard, thus cutting down on the delay at the encoder stage. Video encoding in HEVC requires more computational resources when compared to decoding; this is primarily because of the numerous decisions the encoder has to make to encode a video block optimally. A multitude of factors and variables have to be considered to encode a single coding unit at a minimal cost.

HEVC video compression standard is a block based standard similar to H.264/AVC but it is enriched with many more coding tools than what is available in its predecessors. It has the largest coding unit (CTU) size of 64×64 pixels and the standard allows recursive split right down to the smallest block of 8×8. These variations in coding unit size offer lots of flexibility in the encoding process.

Being a block based compression standard, it relies heavily on motion estimation and compensation as a tool to code video frames. In [18, 19], they reported that 40% of encode time is allotted to motion estimation this reflects the complexities of the encode process due to motion estimation.

Also by design, HEVC has as many as 35 intra-picture prediction modes as opposed to nine modes in H.264/AVC [6]. Also, inter-prediction mode in HEVC has eight prediction units (PU) that the encoder must select one from; whereas in the H.264 the inter prediction units are only four in number [20].

To code a particular CU, the encoder must perform a rate distortion optimization (RDO) decision to determine which of the mode–skip, inter-prediction or intra-prediction–offers the least coding cost; that would be the chosen mode to encode the CU.

Due to these multitude of evaluations that the encoder has to make to optimize the bits budget, which have led to complexities in the encoding process, real time encoding becomes quite challenging in the HEVC. For the reasons stated above and to align with the purpose of the study, the following research questions are addressed:

1. What are the motion estimation algorithms that would reduce the coding delay in the HEVC standard at a minimal trade off in bitrate and video quality?

2. What is the inter-mode decision algorithm that would cut down computational complexities in the HEVC compression standard and still produce acceptable bandwidths and video quality?

3. What is the intra-mode decision algorithm that would cut down encoder run-time in the HEVC standard while maintaining the same video quality and compression ratio?

1.2 Research Objectives

This research seeks to achieve a speedup of encoder run-time by reducing the computational complexities associated with motion estimation, inter-prediction and intra-prediction mode selection. The achievement and implementation of these objectives in the HEVC standard would improve and lead to the speedy deployment of the standard. To achieve this goal, the following research objectives are pursued:

1. To develop and implement faster inter-prediction motion estimation algorithms compatible with the HEVC standard.
2. To develop and implement an inter-prediction mode selection algorithm that would outperform the existing algorithm while maintaining the bandwidths and the quality of the encoded video.
3. To develop and implement an intra-prediction mode selection algorithm that would be capable of selecting intra-prediction modes faster than the existing scheme at an acceptable video quality and bandwidths.

1.3 Research Scope

This study is centered on the main profile of the HEVC, which is the basis of other aspects of the standard such as the 3D-HEVC and HEVC Screen Content Coding. This study examines the inter-prediction motion estimation and compensation, inter-prediction mode selection and the intra-prediction mode selection; since 73% of the encoder run-time is allotted to these units [18, 19].

The video sequences used are from the dataset recommended by the JCT-VC for experimentation on HEVC, and they are drawn from the 8 bits data pool while the color format is derived from the 420 color space. The video sequences or dataset used in the study are as shown in Table 1.1. The video sequences are classified according to the frame resolutions. Class A represents the wide screen quad extended graphic array (WQXGA) with a frame size of 2560 × 1600 pixels. Class B defines the high definition (HD) screen resolution measuring 1920 × 1080 pixels. Class C specifies the 832 × 480 pixels' frame size. The frame size measuring 416 × 240 pixels represents class D. Class E specifies the 720 pixels high definition frame size measuring 1280 × 720 pixels.

For the purpose of update, the first two objectives were benchmarked with the HM14, while the last objective and the consolidated experiments were done on HM16. The HEVC experimental test model (HM) is a software for confirming algorithms. The numbers 14 and 16 appended to 'HM' signifies the versions of the software used in this study.

The computer system used in this study ran on Windows 8.1, 64 bits operating system with Intel Core i7-4700HQ CPU clocked at 2.4GHz with a random access

Table 1.1: Dataset used in this study

Class	Video Sequence	Resolution (pixels)	Frame rate (fps)
A	PeopleOnStreet	2560 × 1600	30
	Traffic	2560 × 1600	30
B	Kimono1	1920 × 1080	24
	ParkScene	1920 × 1080	24
C	BQMall	832 × 480	60
	PartyScene	832 × 480	50
	BasketballDrill	832 × 480	50
D	BasketballPass	416 × 240	50
	BlowingBubbles	416 × 240	50
	RaceHorses	416 × 240	30
E	City	1280 × 720	60
	MobileCalendar-new	1280 × 720	50
	KristenAndSara	1280 × 720	60

memory (RAM) of 12GB.

1.4 Significance of the Study

This study developed and introduced two enhanced fast motion vector search algorithms into the HEVC literature; also an enhanced inter-prediction mode decisions was introduced. An enhanced intra-prediction mode selection algorithm was also added to the HEVC literature. These algorithms that run faster than the benchmarked HEVC algorithms would find applications in live sports video transcoding and video conferencing. In mobile and power constrained devices, these algorithms would be useful especially when deployed on multicore architecture.

1.5 List of Publications

Journal:

1. Edward Jaja, Zaid Omar, Ab Al-Hadi Ab Rahman, and Muhammad Mun'im Zabidi, Efficient motion estimation algorithm for HEVC/H.265 video coding, Information Science and Applications. Springer Berlin Heidelberg, pp. 287–294, 2015. (SCOPUS indexed).

2. Edward Jaja, Zaid Omar, Ab Al-Hadi Ab Rahman, and Muhammad Mun'im Zabidi, Enhanced inter-mode decision algorithm for HEVC/H.265 video coding, Journal of Real Time Image Processing. Springer Berlin Heidelberg, 2015. (ISI indexed Q1 journal).

1.6 Research Contributions

The following research contributions were made in course of this research:

1. This study proposed the pentagon search algorithm for fast motion estimation.
2. The triangular search algorithm was also proposed as a complexity reduction measure for the HEVC standard.
3. A proposal to optimize the Inter-predictions in the HEVC was presented by simplifying the mode decisions over the asymmetric motion partitions (AMP).
4. A proposal to optimize intra-predictions in HEVC was also presented by utilizing direct substitution of the reference samples into the first two rows of the block to be predicted.

1.7 Research Methodology

The layout of research methodology in this thesis is as shown in Figure 1.1. There are three methods that make-up research methodology in this study; these methods are explained in chapters three, four and five. Chapter three covers the motion vector search pattern which is the first method used in this study to reduce computational complexities; Pentagon and triangle search patterns were proposed in this chapter. Chapter four presents enhanced inter-prediction mode decision which is the second method used to achieve the goal of this study; in this chapter, a proposal was presented to optimize inter-prediction mode decision in the HEVC. Chapter five presents the third method proposed in this study to reduce computational complexities; it is the third and last chapter of research methodology.

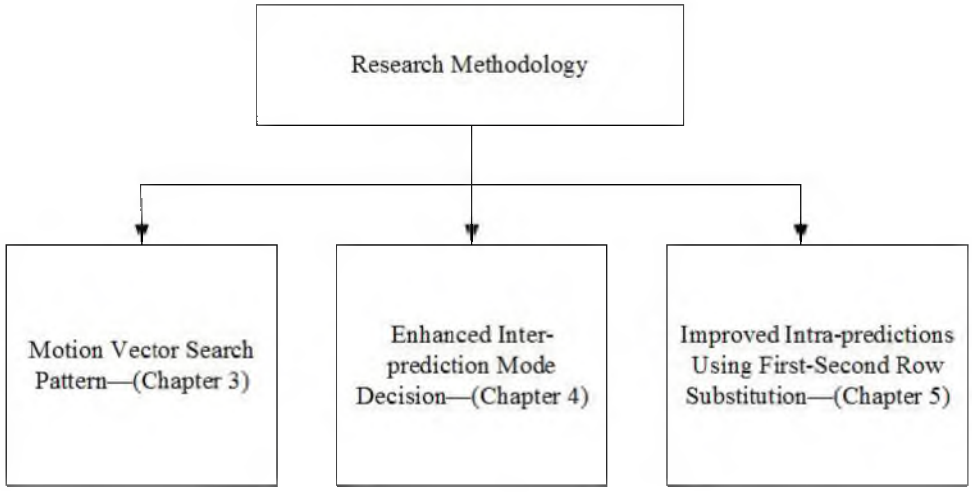

Figure 1.1: Research methodology layout

1.8 Thesis Organizations

This dissertation is organized as follows: Chapter one is the introduction. Chapter two is a review of related literature to the high efficiency video coding (HEVC) standard; evolution of video compression technologies up to the current recommendation are discussed. Chapter three is the first chapter of the methodology; it covers the search patterns as one of the methods used in this research to pursue the objectives of the study. Chapter four is the second chapter of the methodology; it covers the enhanced inter-predictions mode decision in HEVC. This chapter presents the enhanced algorithm for faster inter-prediction mode decision for HEVC. Chapter five is the third methodology chapter; it covers the intra-prediction algorithm proposed in this study for reducing computational complexity in HEVC. Experimental results based on benchmarking the developed algorithms to those of the HEVC were discussed in chapter six. Chapter seven concludes the thesis and also presents suggestions for future works.

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