Algorithm and Architecture of Low Computation FSHEXBS Motion Estimation for Wireless Video Sensor Networks

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Registered since April of year 2011 as Part-time student while working in Intel Microelectronics Sdn. Bhd. Truly experienced the challenges to study while working in industry with heavy workloads. As fresh graduate of Degree who just stepped into industry world, I need to spend additional effort and off hours working to complete my tasks. Out of that, the rest of my time is spent at study this project.

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-CHEONG SEONG CHEE-

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LIST OF ABBREVIATIONS

ME	Motion Estimation
MV	Motion Vector
MPEG	Moving Picture Experts Group
RGB	Red Green Blue
YUV	Luminance (Y), Blue-Luminance (U), Red-Luminance (V)
TSS	Three Steps Search
FSS	Four Steps Search
IFSS	Improved Four Steps Search
DS	Diamond Search
MDSS	Modified Diamond-Square Search
HEXBS	Hexagonal-Based Search
FSHEXBS	Fixed Steps Hexagonal-Based Search
EMOS	Enhanced Modified Orthogonal Search
MB	Mega Bytes
GB	Giga Bytes
FPS	Frame per Second
PSNR	Peak Signal-to-Noise Ratio
CVBS	Composite Video Baseband Signal
FBSME	Fixed Block Size Motion Estimation
VBSME	Variable Block Size Motion Estimation
MSE	Mean Squared Error
SAD	Sum of Absolute Difference
DUT	Design Under Test

LIST OF SYMBOLS

dB	Decibel
Hz	Hertz
kb/s	kilobits per second
ps	Picosecond
s	Second

Algoritma Dan Seni Bina Pengiraan Rendah FSHEXBS Anggaran Gerakan Untuk Rangkaian Penderia Video Tanpa Wayar

ABSTRAK

Projek ini mengkaji kecekapan tenaga daripada beberapa algoritma anggaran gerakan blok pemadanan popular yang boleh digunakan dalam aplikasi rangkaian penderia video tanpa wayar. Anggaran gerakan carian penuh menyediakan kualiti imej yang terbaik tetapi memerlukan kuasa pengiraan yang tinggi. Oleh itu, hanya algoritma anggaran gerakan carian pantas dipertimbangkan untuk penggunaan dalam rangkaian penderia video tanpa wayar, yang secara amnya beroperasi di kawasan pedalaman dan bateri dikekang. Walau bagaimanapun, kualiti imej anggaran gerakan carian pantas juga perlu diambil kira dalam perbandingan. Objektif utama projek ini adalah untuk mereka bentuk anggaran gerakan carian pantas memerlukan kuasa pengiraan yang rendah berdasarkan pemilihan sedia ada iaitu Algoritma Anggaran Gerakan Asas Segi Enam (HEXBS). Ia dipanggil Algoritma Anggaran Gerakan Langkah Tetap Asas Segi Enam (FSHEXBS) kerana nama berasaskan reka bentuk rujukan. FSHEXBS adalah sesuai untuk digunakan dalam aplikasi rangkaian penderia video tanpa wayar kerana penggunaan kuasa adalah kebimbangan utama bagi rangkaian penderia video tanpa wayar manakala kualiti video juga perlu berada dalam julat yang boleh diterima. Julat yang boleh diterima bermakna pemerhatian daripada mata manusia masih mampu untuk mentafsir objek dalam video tanpa gangguan imej yang serius. Oleh itu, FSHEXBS dicadangkan kerana keupayaannya dari segi kuasa pengiraan yang lebih rendah berbanding dengan algoritma anggaran carian pantas yang sedia ada termasuk Carian Tiga Langkah (TSS), Carian Bentuk Berlian-Segi Empat Ubahsuai (MDSS), Carian Asas Enam Segi (HEXBS), Carian Peningkatan Asas Enam Segi (EHEXBS) dan Carian Penuh (FS). Dalam projek ini, algoritma blok diperbandingkan dengan menggunakan dua kriteria iaitu kuasa pengiraan dan kualiti imej. Perbandingan yang dilakukan merangkumi format video QCIF (176x144 pixel), CIF (352x288 pixel), dan 4CIF (740x576 pixel) untuk 10 video penanda aras yang berbeza. Daripada keputusan eksperimen, FSHEXBS memberikan prestasi terbaik yang memenuhi keperluan aplikasi rangkaian penderia video tanpa wayar dengan menawarkan 21.32% peningkatan kualiti imej dan 21.37% penjimatan kuasa pengiraan berbanding dengan HEXBS. Kaedah yang dicadangkan dapat mengurangkan beban kuasa pengiraan sebanyak 95.11% dan pada masa yang sama mempunyai kualiti imej hampir sama berbanding dengan Algoritma Carian Penuh.

Algorithm and Architecture of Low Computation FSHEXBS Motion Estimation for Wireless Video Sensor Networks

ABSTRACT

This project reviews the energy efficiency of several popular block-matching motion estimation algorithms that can be used in wireless video sensor network applications. Full search motion estimation provides the best image quality but requires high computing power. Therefore, only fast search algorithms are considered for deployment in wireless video sensor networks, which generally operate in remote and battery-constrained areas. However, the image quality of fast search algorithms also needs to be considered in the comparison. The main objective of this project is to design a low computation Motion Estimation Module based on the selection of existing Hexagonal-Based Search (HEXBS) algorithm. It is called Fixed Steps Hexagonal-Based Block-Matching Motion Estimation algorithm (FSHEXBS) due to its reference design name. FSHEXBS is suitable to be used in wireless video sensor networks application while power consumption is the key concern for wireless video sensor networks, video quality need to be in acceptable range. Acceptable range means human eyes ball observation is still able to interpret the video frames objects without serious image distortion. Therefore, FSHEXBS is being proposed due to its lower energy consumption capability compared to existing fast search algorithms included Three Steps Search (TSS), Modified Diamond-Square Search (MDSS), Hexagonal-Based Search (HEXBS), Enhanced Hexagonal-Based Search (EHEXBS) and Full Search (FS). In this project, block-matching algorithms are compared by using two criteria that are computation cost/energy consumption, and image quality. Comparison done across QCIF (176x144 pixels), CIF (352x288 pixels), and 4CIF (740x576 pixels) video formats for 10 different benchmark videos. From the experiment results, FSHEXBS gives the best performance that fulfilled the need of wireless video sensor networks video compression application by offering average 21.32% image quality enhancement and 21.37% of computational cost saving compared to HEXBS. The proposed method is able to reduce the computational load by 95.11% and at the same time having almost equal image quality as compared to Full Search algorithm.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Video is constructed by a sequence of still images representing scenes in motion. If video is split, it will becomes image frames. Each image frame is having slight object movement compare to the previous image frame. The number of still images per unit of time is called Frame Rate (Frame/seconds). The higher the number of frame rate, the better the quality of video as the objects movement is more detail. According to research, the minimum frame rate to achieve the illusion of a moving image is about 15 frames per seconds. Normally, 30 frames per second or 60 frames per second to get the better illusion effect for video.

Image is built by combination of pixels depends on the size of image. The number of pixels in width multiply to height names image sizing. For example, a 352 pixels x 288 pixels image (CIF) is having total number of 101376 pixels RGB color data. Each RGB pixel contains 8-bits binary data. Therefore, a total of 811008-bits binary data is used to store a single frame of image. For a 10 seconds 30 fps video, total of 811008-bits x 30 frames x 10 second equals to 30.4128 MB. A 2 hours movie file required 21.384 GB storage where the Frame Size is just Smartphone screen size.

Hence, video file size compression is very important to reduce the storage size needed for video sequence file. In following chapters, video processing will be explained in more detail. Figure 1.1 below illustrated the concept of object movement based on Previous Frame and Current Frame. For 30 fps video, it simply means there are 30 images in sequence flipped over in 1 second. Due to human eyes limitation to view fast movement object, it created perception showing the object is moving.

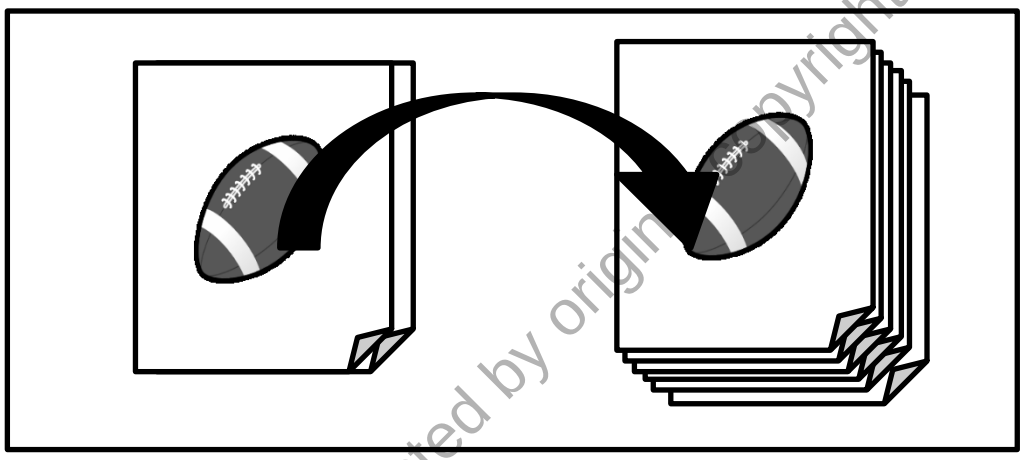


Figure 1.1: Series of images in sequence illustrate object in moving.

1.2 Problem Statement

Wireless video sensor networks are used to monitor geographical areas in battery-constrained conditions. The surveillance nature of many sensor network applications requires a long lifetime. A sensor node after deployed is expected to work for days, weeks or even years without further interventions. Therefore, it is very important to provide a form of energy-efficient surveillance service for a geographical area. The unintended nature of sensor nodes and hazardous sensing environments preclude battery replacement as a feasible solution. Energy constraints in sensor networks unlikely to be solved soon due to slow progress in developing battery capacity.

In order to reduce the power consumption in bit transmission/receptions over wireless video sensor networks, the video captured must be encoded or compressed before it is transmitted to the base station.

To compress video, video processing module is needed. The core of video processing module is motion estimation module that is responsible for 70% of overall module power consumption according to Hussain, M., and Rahmatullah, M.M. (2009). Therefore, design a low power motion estimation algorithm is intended in this thesis. In this project, HEXBS Fast Search Motion Estimation algorithm is chosen to be enhanced is due to after comparison done across several Fast Search ME Algorithms, its characteristic where the balance between reconstructed image quality and computational cost required is suitable to be implemented in wireless video sensor networks. The detail of HEXBS algorithm characteristic can refer to Chapter 2 Literature Review. Figure 1.2 below shows the example of Wireless Video Sensor Network for military usage. Wireless Video Sensors are deployed at various location in war zone to observe or to detect enemy existence. These sensors are placed nearby to each other in order to transmit data gathered wirelessly to control center for further analysis.

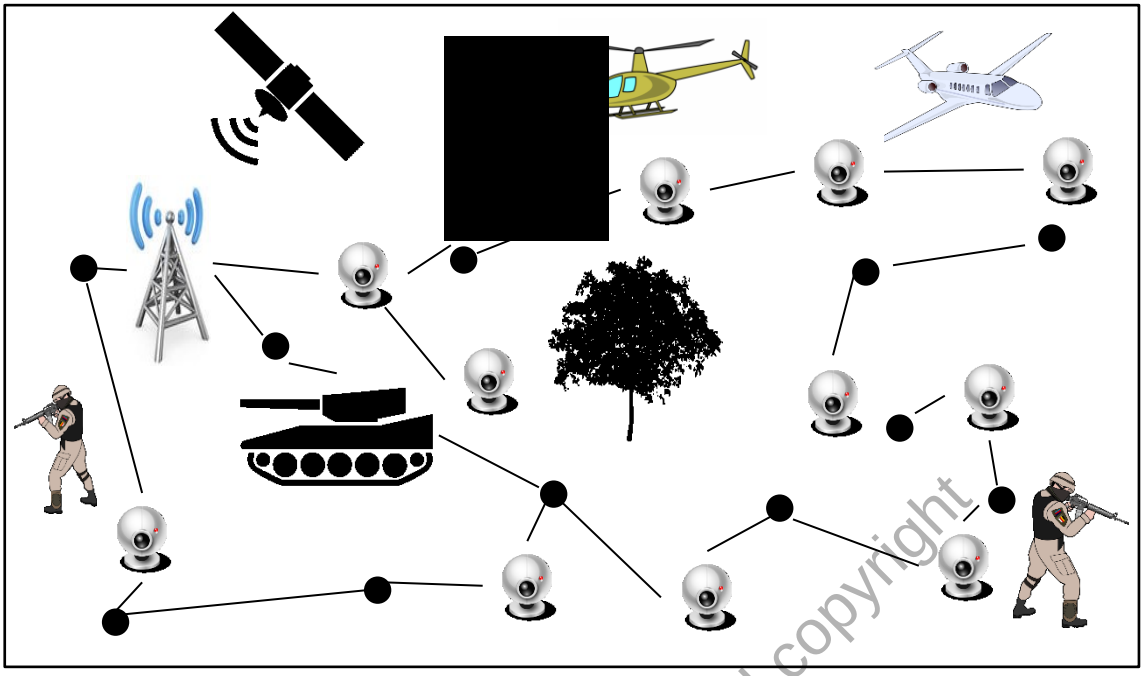


Figure 1.2: Wireless Video Sensor Network usage conceptual photo.

1.3 Objectives

The main objective of this project is to design a low computation motion estimation module with good image quality for wireless sensor networks application. To achieve this, the following items should be completed as well.

I. To study existing Fast Search motion estimation algorithms and analyze them based on image quality and computational cost.

II. To enhance existing Fast Search motion estimation algorithm to have lower computational cost while the image quality can be assured.

III. To design the algorithm by using Matlab and C code to run simulation in order to obtain experimental results for comparison purpose.

IV. To design motion estimation architecture by using Verilog programming and simulate it.

1.4 Scopes

Limitations and the scopes of study are listed at below.

i. Improvement is only done on video processing motion estimation module, as this is the key component that decide the computational cost and compressed video quality.

ii. Motion Estimation algorithm chosen is Fixed Block Size instead of Variable Block Size due to computational cost is higher for Variable Block Size.

iii. New algorithm with better energy efficient and image quality is proposed and evaluated.

iv. Comparison of motion estimation algorithm image quality is done in term of Peak Signal-to-Noise Ratio (PSNR).

v. Comparison of motion estimation algorithm power consumption is done in term of search points number count due to number of search points which is directly proportional to computational cost.

vi. New hardware architecture for proposed motion estimation algorithm is simulated for single Macro Block and single frame. The best match motion vectors are compared using C programming to confirm both are same algorithm.

1.5 Contribution

This thesis contributed towards the following findings.

- Propose enhanced Fixed Block Size Fast Search Hexagonal-Based Motion Estimation algorithm can reduced 21.32% of computational cost and 21.37% better image quality compared to existing HEXBS ME algorithm.
- Propose new Hardware Architecture of Motion Estimation in term of the video frame memory pipeline from 8 bits data width to 32 bits data width for enhanced HEXBS algorithm. Besides, SRAM is replaced by DDR RAM to reduce static power consumption.

1.6 Report Structure

This thesis is structured by five chapters. Chapter 1 introduces the problem statement and objective of the research followed by the scopes of research. Chapter 2 provides the background study information and literature review for video processing concept and existing motion estimation algorithms then explains the proposed ME algorithm and hardware architecture in detail. Chapter 3 explains the methodologies and tools used throughout the research to obtain desired experimental results. Besides, Chapter 3 also elaborate the proposed FSHEXBS ME algorithm in term of C Programming algorithm and Verilog architecture design. After that, Chapter 4 provides the proposed FSHEXBS ME algorithm experimental results from C Programming and Verilog simulation and then evaluate the proposed motion estimation algorithm by

comparing to existing algorithms from various aspects. Lastly, Chapter 5 concludes all the findings and summarize them by correlate to the outcome of this research objective.

1.7 Summary

This chapter introduces the concept of video processing and the importance of it. Besides that, it describes the components of video processing module and emphasize motion estimation module is the most important module in the design as it contributes to 70% of overall power consumption according to Hussain, M., and Rahmatullah, M.M. (2009). This chapter also discusses about the power consumption concern in Wireless Sensor Networks usage and proposes to develop energy efficient motion estimation algorithm to enhance it. The contribution of this research is to design lower computational cost and better image quality motion estimation algorithm. In next chapter, literature review and background of video processing module and motion algorithms will be explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains the background of video processing module in detail and its components especially motion estimation module. It includes the comparison between hardware oriented and software oriented video processing. Besides this, the difference between Fixed Block Size and Variable Block Size Motion Estimation Algorithms will be explained meanwhile Full Search algorithm and Fast Search algorithms will be covered.

2.2 Background Theory

2.2.1 Analog and Digital Video

Analog Video also called as composite video constructed by video signal transferred by an analog signal that contains superimposed light beams by Red, Green, and Blue. The original video recording method that stores continuous waves of red, green and blue intensities. In analog video, the number of rows is fixed. There are no real columns, and the maximum detail is determined by the frequency response of the analog system according to Encyclopedia Analog Video. For motion estimation purpose, video frame has to be in luminance metric without the need to consider color difference

to avoid difficulty in computation. Therefore, RGB is required to be converted to YUV color format where Y is represents brightness in black & white or luma value while UV are represent Chrominance or color code. Figure 2.1 at below illustrated the conversion encoding from RGB to YUV so that motion estimation module can compute the object movement via Y (luma).

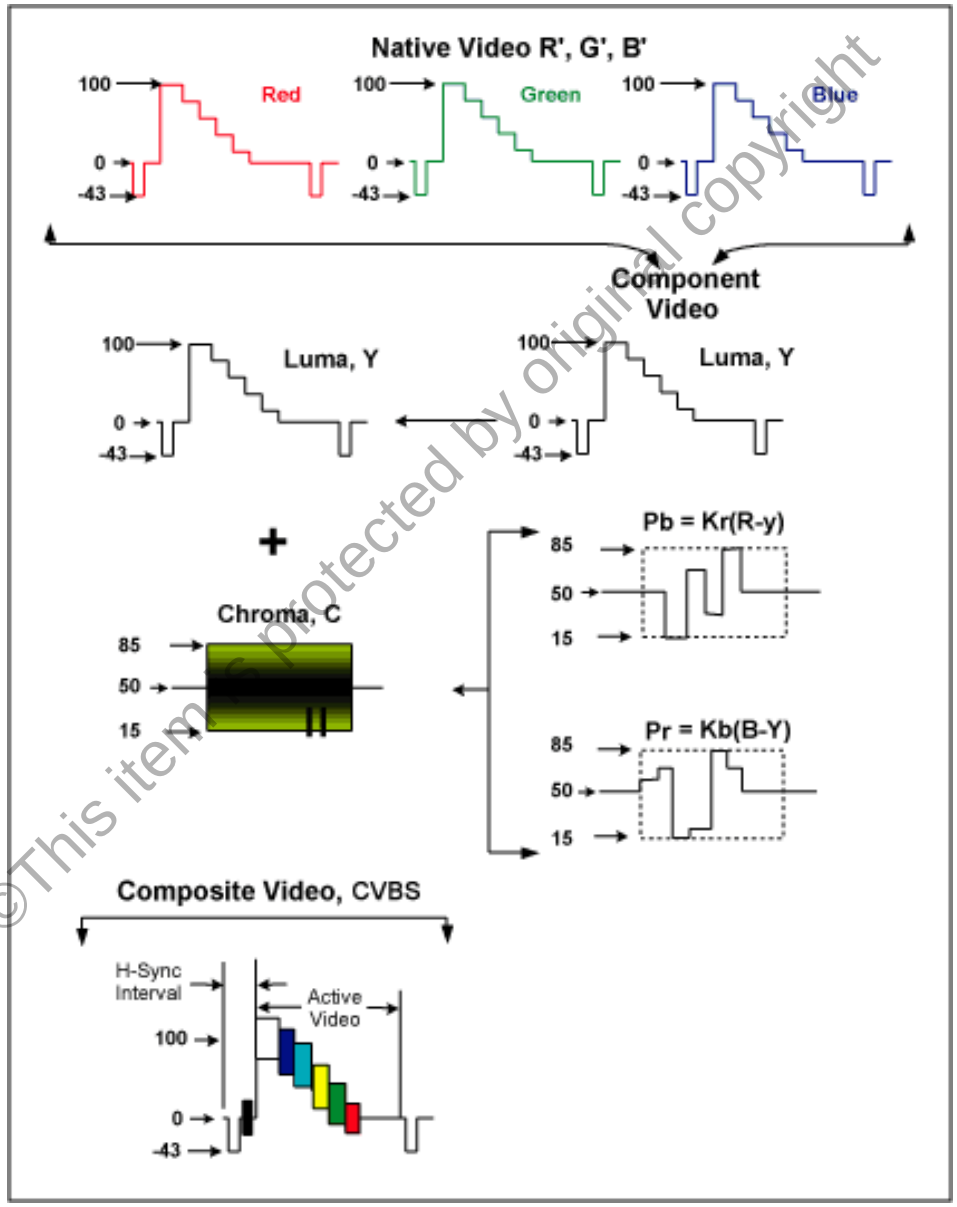


Figure 2.1: Analog encoding from RGB to YUV by referring to Understand Analog Video Signals in Maxim Integrated Inc.

Digital Video comprises a series of orthogonal bitmap digital images displayed in rapid succession at a constant frame rate. Every orthogonal bitmap digital image contains a raster of pixels. Example of pixel in digital picture is shown in Figure 2.3. These pixels are built by RGB color model where each pixel holds 8-bits of binary that represents the corresponded RGB color code as shown in Figure 2.2. Frame rate, also known as frame frequency and its unit is frames per second (fps). It is important in produces unique consecutive image video. For human visual system, it can process 10 to 12 separated images per second. To perceive them, the minimum video frame rate need to be at least 15 fps. Normally 16 fps, 30 fps, 50 fps and 60 fps are used in various electronic devices to provide different video quality to users.

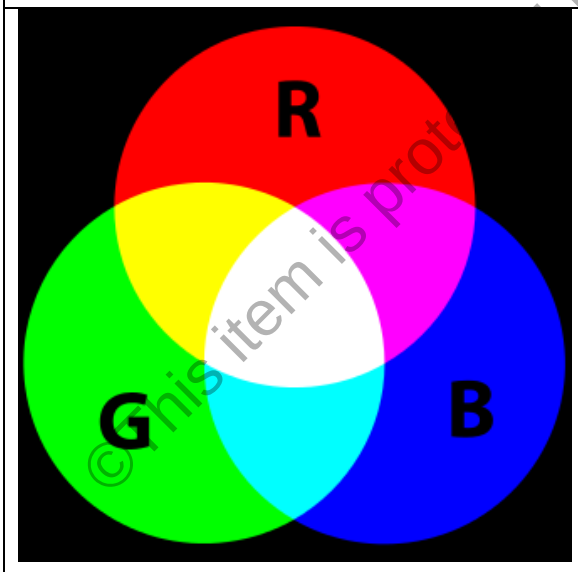
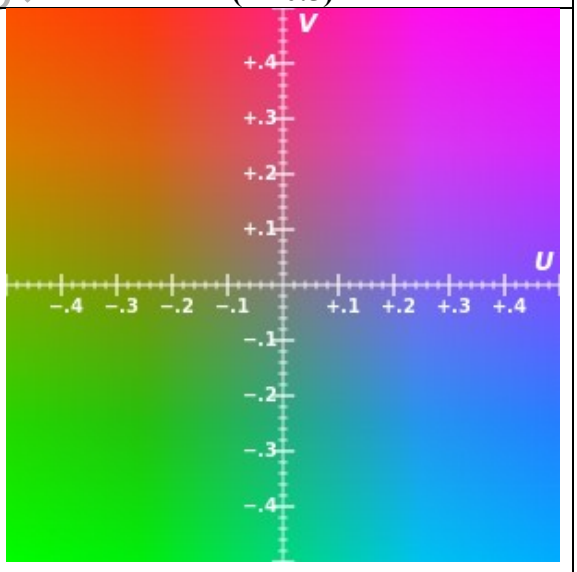
RGB Color Model for Digital Video	YUV Color Plane for Analog Video (Y=0.5)
	

Figure 2.2: RGB Color Model for Digital Video and YUV Color Plane for Analog Video by referring from Colorizer.