LOW ENERGY MOTION ESTIMATION HARDWARE DESIGNS FOR H.264 MULTIVIEW VIDEO CODING

by

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Submitted to the Graduate School of Engineering and Natural Sciences
in partial fulfillment of
the requirements for the degree of
Master of Science

Sabancı University
August 2015

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DATE OF APPROVAL: 01/09/2015

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Keywords: H.264, Multiview Video Coding, Motion Estimation, Hardware Design, FPGA.

ABSTRACT

Multiview Video Coding (MVC) is the process of efficiently compressing stereo (2 views) or multiview video signals. The improved compression efficiency achieved by H.264 MVC comes with a significant increase in computational complexity. Temporal prediction and inter-view prediction are the most computationally intensive parts of H.264 MVC.

Therefore, in this thesis, we propose an H.264 MVC full search motion estimation hardware for implementing the temporal and inter-view predictions including several novel energy reduction techniques. The proposed motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 FPGA. The FPGA implementation is capable of processing 60 frames per second of VGA size stereo view video sequence. It consumes 65% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

We also propose a vector prediction based fast motion estimation algorithm for reducing the energy consumption of H.264 MVC motion estimation hardware with additional very small PSNR loss and bitrate increase. We also propose an H.264 MVC motion estimation hardware for implementing the proposed fast motion estimation algorithm. The proposed motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 FPGA. The FPGA implementation is capable of processing 92 frames per second of VGA size three view video sequence. It consumes 91% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

H.264 ÇOK BAKIŞLI VİDEO KODLAMA İÇİN DÜŞÜK ENERJİ TÜKETİMLİ HAREKET TAHMİNİ DONANIM TASARIMLARI

Yusuf AKŞEHİR

EE, Yüksek Lisans Tezi, 2015
Tez Danışmanı: Doç. Dr. İlker HAMZAOĞLU

Anahtar Kelimeler: H.264, Çok Bakışlı Video Kodlama, Hareket Tahmini, Donanım Tasarımı, FPGA.

ÖZET

Çok Bakışlı Video Kodlama (ÇBVK), stereo (iki bakışlı) veya çok bakışlı video sinyallerini etkili bir şekilde sıkıştırma işlemidir. H.264 ÇBVK sıkıştırma verimliliğini arttırmıştır, fakat hesaplama karmaşıklığını da belirgin bir biçimde arttırmıştır. Zamansal öngörü ve bakışlar arası öngörü, H.264 ÇBVK'nın en çok işlem yapılan kısımlarıdır.

Bu nedenle, bu tezde H.264 ÇBVK zamansal ve bakışlar arası öngörü yapan ve enerji tüketimini azaltan bazı özgün teknikler içeren bir tam arama hareket tahmini donanımı önerdik. Önerilen donanım Verilog HDL ile gerçeklenmiş ve Xilinx Virtex-6 FPGA'sına yerleştirilmiştir. Donanımın FPGA gerçeklemesi VGA çözünürlüklü stereo video sinyalini saniyede 60 çerçeve hızında işleyebilmektedir. Özgün tekniklerin olmadığı H.264 ÇBVK tam arama hareket tahmini donanımından çok az PSNR kaybı ve bit hızı artışı ile birlikte %65 daha az enerji harcamaktadır.

Bu tezde ayrıca H.264 ÇBVK hareket tahmini donanımının çok az ek PSNR kaybı ve bit hızı artışı ile birlikte enerji tüketimini azaltmak için vektör tahmini tabanlı bir hızlı hareket tahmini algoritması önerdik. Ayrıca bu algoritmayı gerçekleyen bir H.264 ÇBVK hareket tahmini donanımı da önerdik. Önerilen donanım Verilog HDL ile gerçeklenmiş ve Xilinx Virtex-6 FPGA'sına yerleştirilmiştir. Donanımın FPGA gerçeklemesi VGA çözünürlüklü üç bakışlı video sinyalini saniyede 92 çerçeve hızında işleyebilmektedir. Özgün tekniklerin olmadığı H.264 ÇBVK tam arama hareket tahmini donanımından çok az PSNR kaybı ve bit hızı artışı ile birlikte %91 daha az enerji harcamaktadır.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor Assoc. Prof. Dr. İlker Hamzaoğlu for his support, motivation and knowledge. He aided me with his experience throughout the research and the writing of this thesis and I appreciate it very much.

I also would like to thank to all members of System-on-Chip Design Lab, Kamil Erdayandı, Ercan Kalalı, Yusuf Adıbelli, Zafer Özcan, Serkan Yaliman, Hasan Azgın and Erdem Özcan. They were always supportive and helping when I was in need.

This thesis project was supported by Scientific and Technological Research Council of Turkey (TUBITAK), so I thank TUBITAK and Sabanci University for this opportunity.

Lastly I want to thank all my family and friends, for their endless support and motivation. I especially thank my mother, my sister and my father for never giving up on me.

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LIST OF ABBREVIATIONS

3D	:	Three Dimensional
BM	:	Block Matching
BRAM	:	Block Random-Access Memory
CIF	:	Common Intermediate Format
DFF	:	D Flip-Flop
FPGA	:	Field-Programmable Gate Array
FSMEA	:	Full Search Motion Estimation Algorithm
GOP	:	Group of Pictures
HDL	:	Hardware Description Language
IR	:	Interview Reference
IRVPH	:	Interview Reference Vector Prediction Hardware
JMVC	:	Joint Multiview Video Coding
LR	:	Left Temporal Reference
LRVPH	:	Left Reference Vector Prediction Hardware
LUT	:	Look-up Table
ME	:	Motion Estimation
MVC	:	Multiview Video Coding
PE	:	Processing Element
PSNR	:	Peak Signal-to-Noise Ratio
RR	:	Right Temporal Reference
RRVPH	:	Right Reference Vector Prediction Hardware
QP	:	Quantization Parameter
RTL	:	Register Transfer Level
SAD	:	Sum of Absolute Differences
VCD	:	Value Change Dump
VPBFMEA	:	Vector Prediction Based Fast Motion Estimation Algorithm
VGA	:	Video Graphics Array

XGA	:	Extended Graphics Array

Chapter 1

INTRODUCTION

Since H.264 video compression standard has higher video compression efficiency than previous video compression standards, it is already started to be used in many consumer electronic devices [1, 2]. Motion estimation (ME) is used for compressing a video by removing the temporal redundancy between the video frames. It is the most computationally intensive part of video encoder hardware. The improved compression efficiency achieved by motion estimation in H.264 standard comes with an increase in computational complexity.

Block matching (BM) is used for ME in H.264 standard. BM partitions the current frame into non-overlapping NxN rectangular blocks and finds a MV for each block by finding the block from the reference frame in a given search range that best matches the current block. Sum of Absolute Differences (SAD) is the most preferred block matching criterion [3]. The SAD value of a search location defined by the motion vector d(dx,dy) is calculated as below where c(x,y) and r(x,y) represent current and reference frames, respectively. The coordinates (i,j) denote the offset locations of current and reference blocks of size NxN.

$$SAD(\vec{d}) = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1}\left|c(x+i, y+j) - r(x+i+d_x, y+j+d_y)\right| \tag{1.1}$$

Multiview Video Coding (MVC) is the process of efficiently compressing stereo (2 views) or multiview video signals. MVC has many applications such as 3 dimensional (3D) TV and free viewpoint TV. As shown in Fig. 1.1, each view in a multiview video can be independently coded by an H.264 video encoder. However, in order to efficiently compress a multiview video, in addition to removing the temporal redundancy between the frames of a view, the redundancy between the frames of neighboring views should also be removed. Therefore, H.264 standard is extended with MVC [4, 5, 6].

As shown in Fig. 1.2, H.264 MVC codes the frames of the synchronized views by predicting the frames from both the other frames in the same view and the other frames in the neighboring views. In this way, it reduces the bitrate without reducing the quality of the reconstructed video in comparison to coding each view independently. However, the improved compression efficiency achieved by H.264 MVC comes with a significant increase in computational complexity.

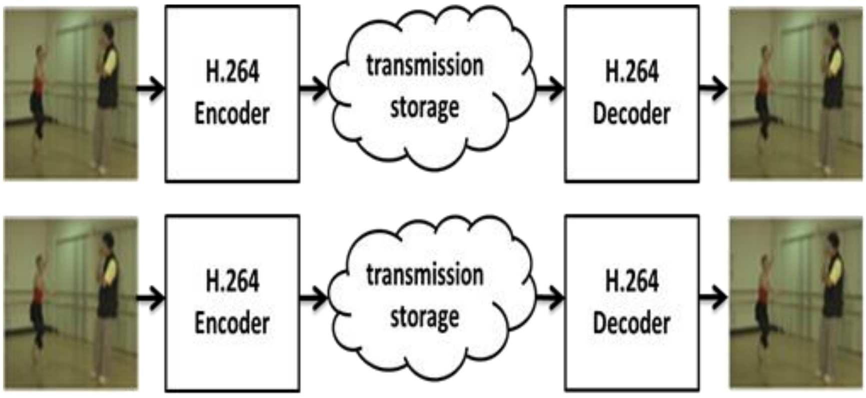

Figure 1.1 H.264 Simulcast Coding For Stereo Video [4]

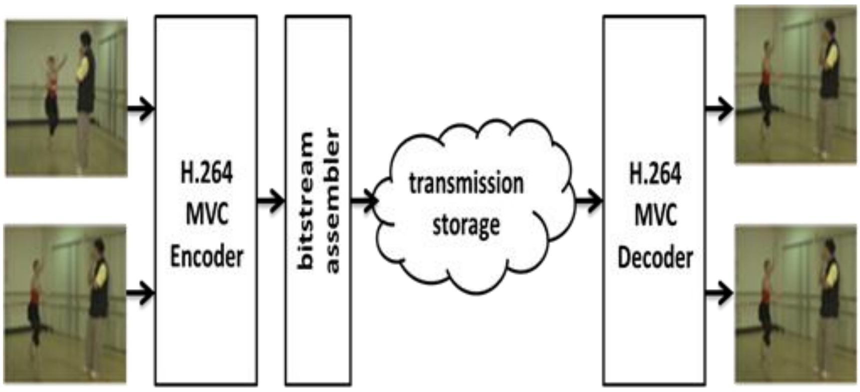

Figure 1.2 H.264 Multiview Coding For Stereo Video [4]

An H.264 MVC prediction structure for 5 views captured with 5 linearly arranged cameras is shown in Fig. 1.3 [7]. In this prediction structure, eight temporal pictures are considered to form a group of pictures (GOP). The first picture of a GOP (black pictures in Fig. 1.3) is called key picture, and the other pictures of a GOP are called nonkey pictures. The key pictures of the first view (I frames) are intra-coded. The blocks in an I frame are predicted from spatially neighboring blocks in the same frame. The key pictures of the other views (P frames) are inter-coded. The blocks in a P frame are predicted from the blocks in the key picture of previous view. Hierarchical B pictures with 3 levels are used for temporal prediction. The nonkey pictures of the first view are inter-predicted only from the previous and future pictures in the same view. The nonkey pictures of the other views are inter-predicted both from the previous and future pictures in the same view and the B pictures in the previous view.

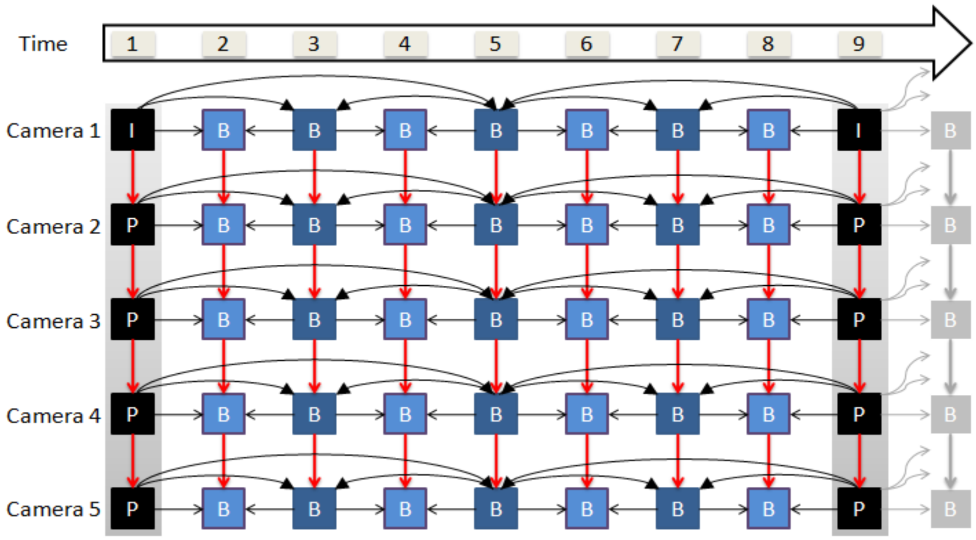

Figure 1.3 An H.264 Multiview Coding Prediction Structure [7]

1.1 Thesis Contribution

Temporal prediction (between pictures in the same view) and inter-view prediction (between pictures in the neighboring views) are the most computationally intensive parts of H.264 MVC. Therefore, in this thesis, we propose an H.264 MVC full search motion estimation hardware for implementing the temporal and inter-view predictions including several novel energy reduction techniques [12], [16]. The proposed H.264 MVC motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 11.5. The FPGA implementation consumes 13303 slices, 40598 LUTs, 22024 DFFs and 60 BRAMs, and works at 125 MHz. The FPGA implementation is capable of processing 30*8=240 frames per second of CIF (352x288) size 8 view video sequence or 30*2=60 frames per second of VGA (640x480) size stereo (2 views) video sequence. It consumes 65% less energy than

H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

We also propose a vector prediction based fast motion estimation algorithm for reducing the energy consumption of H.264 MVC motion estimation hardware by utilizing the correlation between motion vectors of neighboring macro blocks with additional very small PSNR loss and bitrate increase. We also propose an H.264 MVC motion estimation hardware for implementing the proposed fast motion estimation algorithm. The proposed motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 13.4. The FPGA implementation consumes 22942 slices, 60596 LUTs, 51942 DFFs and 36 BRAMs, and works at 76 MHz. The FPGA implementation is capable of processing 92 frames per second of VGA size three view video sequence. It consumes 91% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

Chapter 2

LOW ENERGY MOTION ESTIMATION HARDWARE

We propose an H.264 MVC full search motion estimation (ME) hardware for implementing the temporal and inter-view predictions including several novel energy reduction techniques [12], [16]. The first technique is searching only the right side of the search window in the neighboring view during inter-view prediction, because of the camera positions in Ballroom and Vassar multiview videos with 8 views. The second technique is performing full search motion estimation during inter-view prediction for the current block in a search window of size 16 ([0, +16]) if the previous disparity vector is smaller than 17, in a search window of size 32 ([0, +32]) if previous disparity vector is smaller than 33, otherwise in a search window of size 48 ([0, +48]). In addition, if previous SAD value is larger than a threshold value, the size of the search window is increased by 16. Therefore, search window size can be at most 64 ([0, +64]). The SAD values obtained by motion estimation in JMVC 3.01 H.264 MVC software are analyzed to determine this threshold value. Since most of the SAD values were smaller than 2000, the SAD threshold value is set to 1500. The last technique is using different search window sizes for different frames in the GOP for temporal prediction. For coding 5^{th} frame we used [-32, +32] search window, for coding 2^{nd}, 3^{rd}, 4^{th}, 6^{th}, 7^{th} and 8^{th} frames we used [-16, +16] search window.

The block diagram of the proposed low energy H.264 MVC ME hardware implementing the temporal and inter-view prediction structure shown in Fig. 1.3 and the novel energy reduction techniques is shown in Fig. 2.1. Since, in H.264 MVC prediction structures, the blocks in a picture is searched in at most three reference pictures (left temporal reference picture, right temporal reference picture and inter-view reference picture), the proposed H.264 MVC ME hardware has three full search ME hardware working in parallel. The performance of the proposed H.264 MVC ME hardware can be increased by using additional full search ME hardware at the expense of more area.

The block diagram of a full search ME hardware is shown in Fig. 2.2. This ME hardware is designed based on the 256 Processing Element (PE) ME hardware with fix search window size proposed in [8]. The pixels in the search window searched by a ME hardware are stored in 20 32*80 bit block RAMs (BRAM) as shown in Fig. 2.3. In the figure, (x, y) show the position of the pixel in the search window.

In LR ME hardware, the current block in the current picture is searched in the search window in the left temporal reference picture in the same view. In RR ME hardware, the current block in the current picture is searched in the search window in the right temporal reference picture in the same view. In IR ME hardware, the current block in the current picture is searched in the search window in the inter-view reference picture in the neighboring view. In IR ME hardware, search window size is not fixed. The search window size for the current block is determined based on the previous disparity vector.

The blocks in some of the pictures in H.264 MVC prediction structures are searched in less than three reference pictures. For example, since there is no inter-view reference picture for the pictures in the first view, the blocks in these pictures are not searched in inter-view reference pictures. Therefore, IR ME hardware is not used for these blocks. Similarly, the blocks in key pictures in each view are not searched in temporal reference pictures. Therefore, LR ME hardware and RR ME hardware are not used for these blocks.

Each ME hardware determines the motion vector with the minimum SAD value in its search window. In addition, an average search block is computed by averaging the search blocks pointed by the best motion vectors found by LR ME hardware and RR ME hardware, and the SAD value for this average block is computed. Finally, the motion vector with the minimum SAD value among these 4 motion vectors is determined.

Each ME hardware first reads the current macro block in 16 clock cycles and stores it in the PE array. Then, in each clock cycle, it reads 4*5=20 search window pixels and stores them into 5 BRAMs, 4 pixels (32 bits) into each BRAM. After the search window pixels are stored into first 16 addresses of first 5 BRAMs, ME hardware starts SAD calculation. It calculates the SAD values and loads the search window pixels into BRAMs in parallel. BRAMs are loaded in groups of 5 in 4*80=320 clock cycles. SAD values are calculated by PE array and adder tree. PE array implements data reuse technique by shifting the search window pixels to down, up, and right in order to reduce BRAM accesses. ME hardware compares the SAD values as they are calculated and determines the motion vector with minimum SAD value. 256 PE ME hardware finds the motion vector with minimum SAD value for the 16x16 current macro block in a [-32, +32] size search window in 4128 clock cycles.

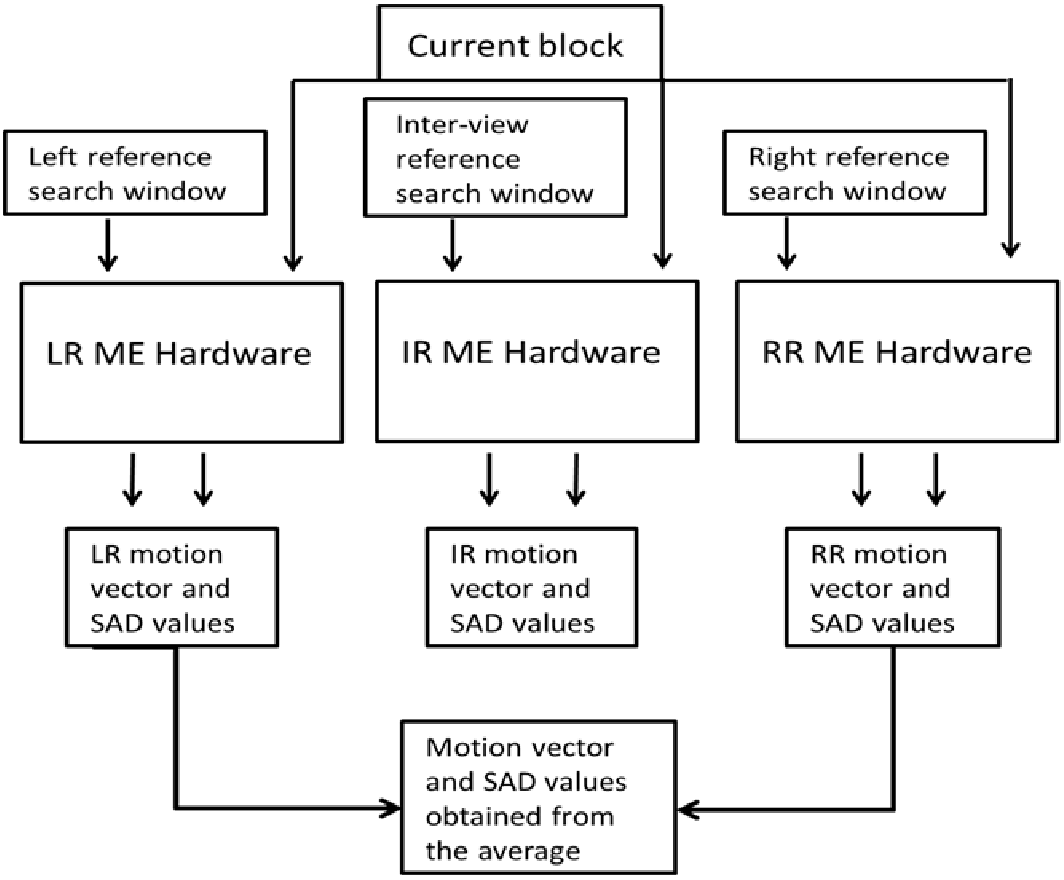

Figure 2.1 H.264 MVC ME Hardware

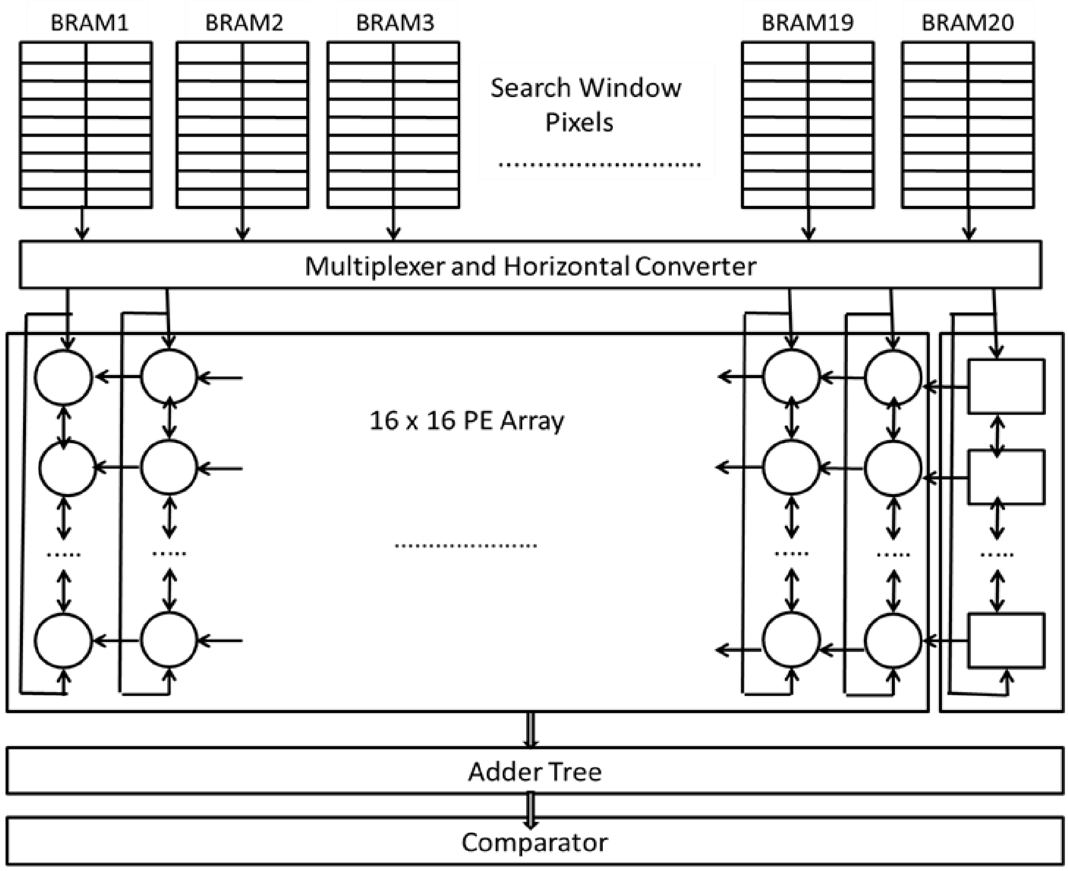

Figure 2.2 256 PE ME Hardware With Search Window Memory

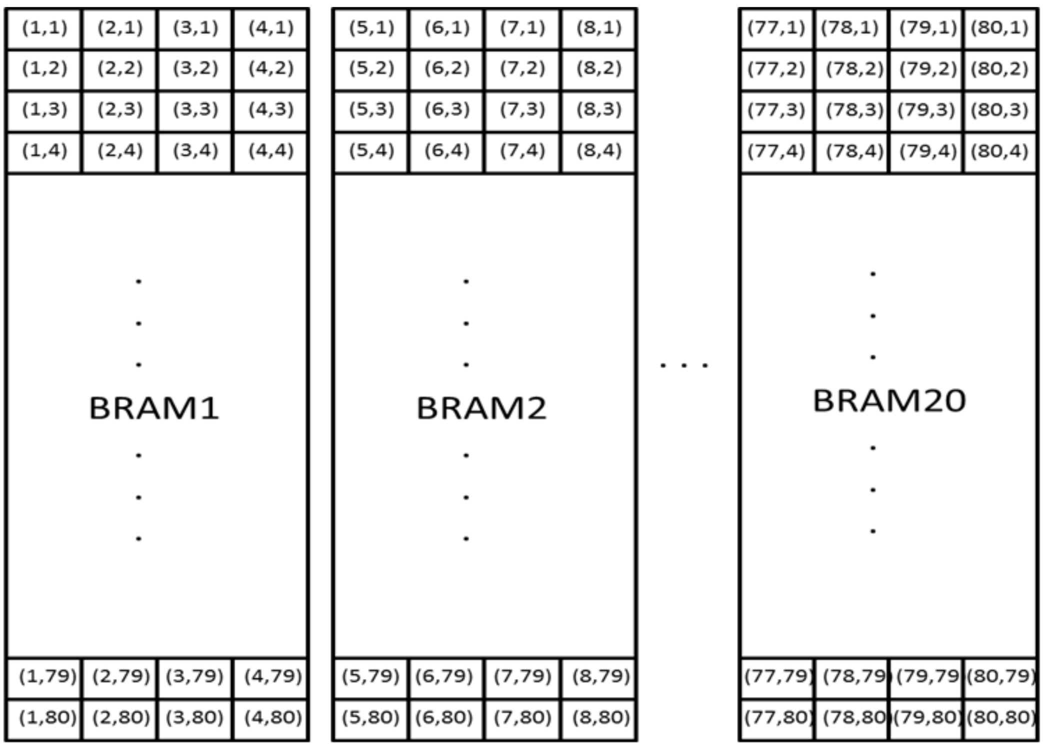

Figure 2.3 BRAM Organization

The proposed H.264 MVC ME hardware including the novel energy reduction techniques is implemented in Verilog HDL. The Verilog RTL codes are mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 11.5. The FPGA implementation is verified with post place & route simulations using Mentor Graphics Modelsim 6.1c. It consumes 13303 slices, 40598 LUTs, 22024 DFFs and 60 BRAMs, and it works at 125 MHz.

The FPGA implementation processes (performs temporal and inter-view predictions) 5th picture in a GOP in 41.6ms. It processes the other B pictures in the first view in 10.4 ms, and it processes the other pictures in the other views in 14.44ms. Since varying search window sizes are used during inter-view prediction, these timing values are calculated by using the search window size results obtained by JMVC 3.01 H.264 MVC software and the timing results obtained by post place & route timing simulations. The FPGA implementation processes a GOP of a VGA (640x480) size stereo (2 views) video sequence in 41.6*2 + 10.4*6 + 14.44*7 = 246.68 ms. Therefore, it can process 30*2=60 fps of VGA (640x480) size stereo (2 views) video sequence. Similarly, it can process 30*8=240 fps of CIF (352x288) size 8 view video sequence.

We estimated the power consumptions of both the H.264 MVC ME hardware not including the novel energy reduction techniques, which uses [-32, +32] fix size search window for both temporal and inter-view predictions, and the H.264 MVC ME hardware including the novel energy reduction techniques on the same FPGA using Xilinx XPower tool for several frames of VGA (640x480) size Ballroom multiview video. In order to estimate the power consumption of an H.264 MVC ME hardware, timing simulation of its placed & routed netlist is done at 125 MHz using Mentor Graphics ModelSim SE for some macro blocks of several Ballroom video frames. The signal activities of these timing simulations are stored in VCD files, and these VCD files are used for estimating the power consumption of that H.264 MVC ME hardware using Xilinx XPower Analyzer tool.

The power and energy consumption results for the first one fourth of the macro blocks in the second frame in view 3 of first GOP are shown in Table 2.1. The power and energy consumption results for middle one tenth of the macro blocks in all the frames of the third GOP are shown in Table 2.2. These results show that the novel techniques reduce the energy consumption of the H.264 MVC ME hardware significantly.

	Average Power (mW)	Time (μs)	Energy (mj)	Energy Reduction (%)
Without Novel Techniques	1489.62	10079	15.41	0
With Novel Techniques	1529.82	2901	4.32	71.97

Table 2.1 Power And Energy Consumption Results For A Frame

	Average Power (mW)	Time (μs)	Energy (mj)	Energy Reduction (%)
Without Novel Techniques	1425.62	4141	5.90	0
With Novel Techniques	1478.50	1525	2.25	61.78

Table 2.2 Power And Energy Consumption Results For Several Frames

The H.264 MVC ME hardware proposed in [9] consumes 4308 slices, 9876 LUTS, and 103 BRAMs in a Xilinx Virtex-6 XC6VLX240T FPGA. It works at 258 MHz and processes 30 fps of 4 view HD 1080p size video sequence. Since the H.264 MVC ME hardware proposed in [9] implements fast search ME and the proposed H.264 MVC ME hardware implements full search ME, the H.264 MVC ME hardware proposed in [9] is both smaller and faster than the proposed H.264 MVC ME hardware at the expense of worse rate distortion performance.

Chapter 3

VECTOR PREDICTION BASED FAST MOTION ESTIMATION ALGORITHM AND HARDWARE

3.1 Vector Prediction Based Fast Motion Estimation Algorithm

We propose a fast H.264 MVC motion estimation algorithm for reducing the energy consumption of H.264 MVC motion estimation hardware with very small PSNR loss and bitrate increase. Objects in video frames usually occupy more than one macroblock (MB). Therefore, there is usually a correlation between motion vectors of neighboring MBs. The proposed vector prediction based fast motion estimation algorithm (VPBFMEA) determines possible candidate motion vectors for the current MB by utilizing this correlation, and it first searches the search locations pointed by these candidate motion vectors. It then performs full search in a very small search window pointed by the candidate motion vector with minimum SAD.

The candidate motion vectors that will be used for inter-view and temporal predictions of the current MB are shown in Fig. 3.1. Since the MBs in a frame are coded in raster scan order, the red MBs in Fig. 3.1 are not yet coded, and therefore they do not have a motion vector when the current MB is being coded. The green MBs in Fig. 3.1 are coded, and therefore they have inter-view and temporal motion vectors when the current MB is being coded. The proposed algorithm uses the inter-view and temporal motion vectors of 49 green MBs (4 previously coded neighboring MBs in current frame and 9 previously coded neighboring MBs in five neighboring frames) as candidate motion vectors for the current MB. The five neighboring frames are previous and future reference frames in the current view, and same, previous and future reference frames in the previous view.

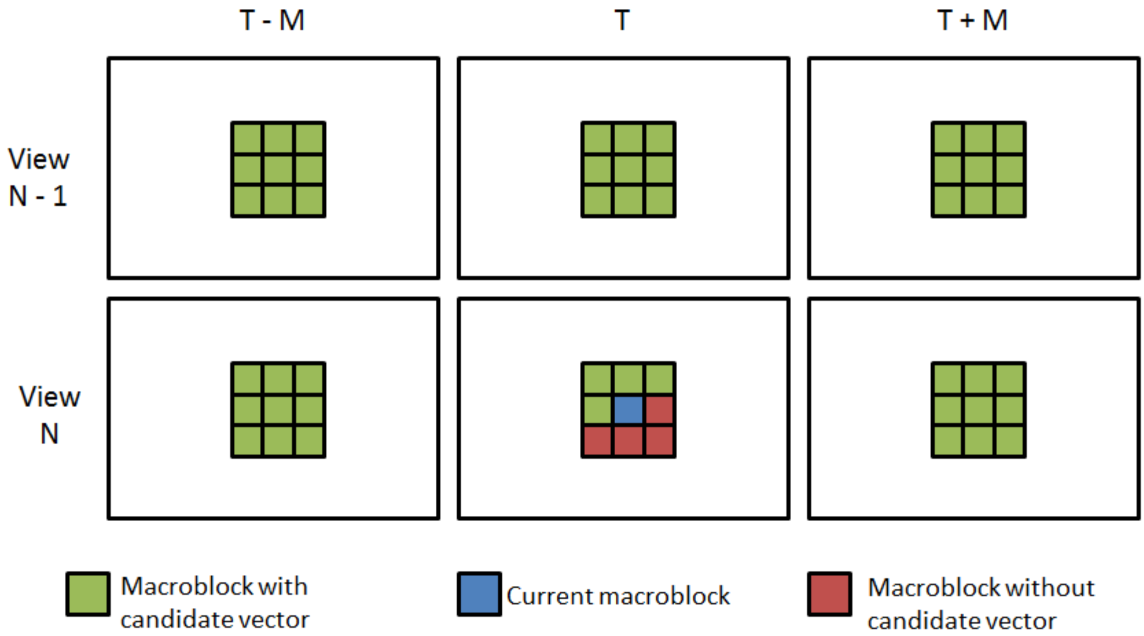

Figure 3.1 Candidate Motion Vectors

The proposed vector prediction based fast motion estimation algorithm calculates the SAD values of all left temporal candidate motion vectors for left temporal prediction, the SAD values of all right temporal candidate motion vectors for right temporal prediction and the SAD values of all inter-view candidate motion vectors for inter-view prediction. In most cases, the current MB has 49 left temporal candidate motion vectors, 49 right temporal candidate motion vectors, and 49 inter-view candidate motion vectors. However, as shown in Fig. 3.2, in some cases the current MB may have less candidate motion vectors. Because, the current MB may be on the corner or edge and it may not have 9 neighboring MBs. The current frame may not have previous or future reference frame in the current view and in the previous view.

The proposed algorithm then performs full search in three very small search windows pointed by the left temporal candidate motion vector with minimum SAD, the right temporal candidate motion vector with minimum SAD, the inter-view candidate motion vector with minimum SAD, and determines the left temporal motion vector with minimum SAD, right temporal motion vector with minimum SAD, inter-view motion vector with minimum SAD.

It finally selects the motion vector among these three motion vectors with minimum SAD as the motion vector of the current MB.

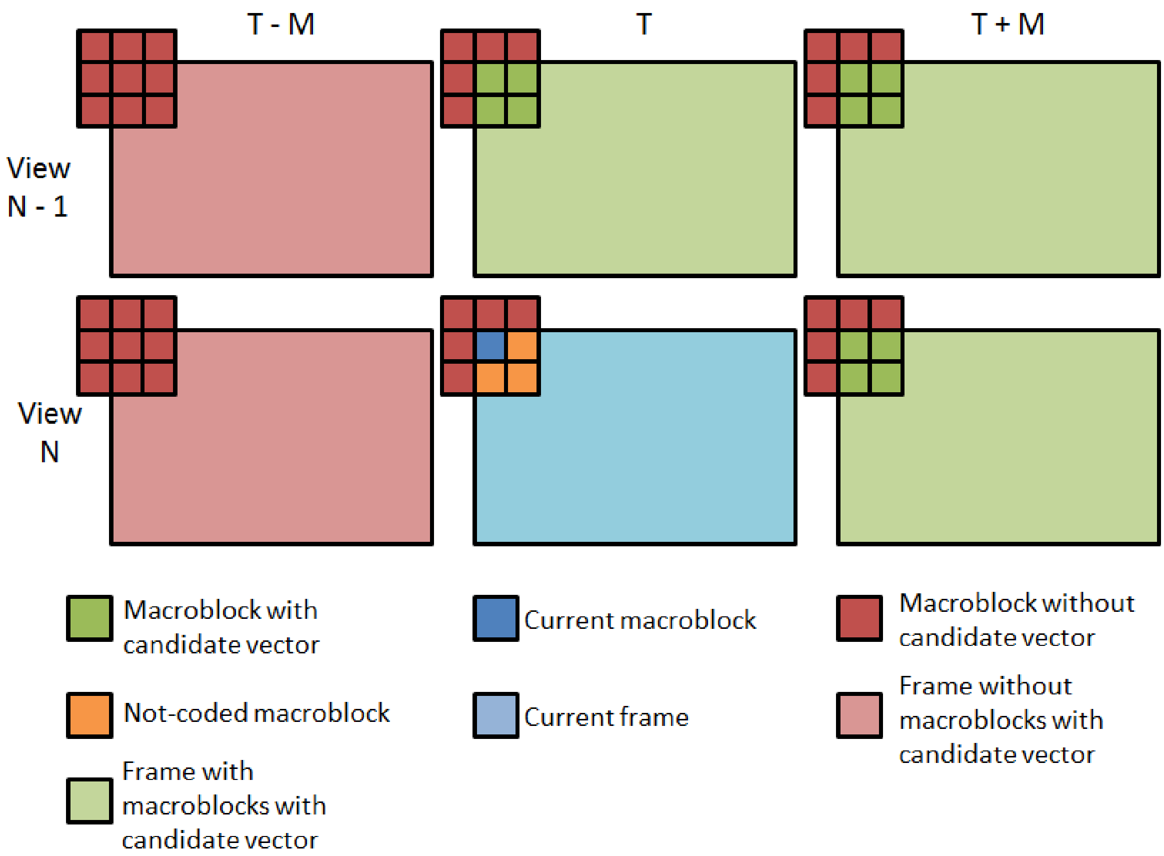

Figure 3.2 A Sample Case For Candidate Motion Vectors

Since there is no previous view for the first view, inter-view prediction is not done in the first view. In the first view, 1^{st} frame in a GOP is always intra-coded. Temporal prediction for 5^{th} frame in a GOP is performed with full search motion estimation (FSME) using the previous reference frame and the future reference frame shown in Fig. 1.3. Temporal prediction for the other frames in a GOP is performed with VPBFME. Temporal prediction for each frame uses candidate motion vectors in current frame. In addition, temporal predictions for 3^{rd} and 7^{th} frames use candidate motion vectors in 5^{th} frame. The candidate motion vectors from 5^{th} frame are used after dividing them by 2, because of the difference between distances of reference frames as shown in Fig. 1.3. Temporal predictions for 2^{nd}, 4^{th}, 6^{th}, and 8^{th} frames use candidate motion vectors in 3^{rd} frame, 3^{rd} and 5^{th} frames, 5^{th} and 7^{th} frames, 7^{th} frames, respectively. The candidate motion vectors from 5^{th} frame are used after dividing them by 4, and the candidate motion vectors from 3^{rd} and 7^{th} frames are used after dividing them by 2, because of the same reason.

In the second view, no temporal prediction for 1st frame in a GOP is performed. Temporal prediction for 5^{th} frame in a GOP is performed same as the temporal prediction for 5^{th} frame in a GOP in the first view. Temporal prediction for the other frames in a GOP is performed same as the temporal prediction for the other frames in a GOP in the first view but with additional candidate motion vectors in same, previous and future reference frames in the first view. Temporal predictions for 2^{nd}, 3^{rd}, 4^{th}, 6^{th}, 7^{th} and 8^{th} frames use additional candidate motion vectors in 2^{nd} and 3^{rd} frames, 3^{rd} and 5^{th} frames, 3^{rd}, 4^{th} and 5^{th} frames, 5^{th}, 6^{th} and 7^{th} frames, 5^{th} and 7^{th} frames, 7^{th} and 8^{th} frames in the first view, respectively. Inter-view predictions for 1^{st} and 5^{th} frames in a GOP are performed with FSME using the inter-view reference frame in the first view. Inter-view prediction for the other frames in a GOP is performed with VPBFME. Inter-view prediction for each frame uses candidate motion vectors in current frame. In addition, inter-view predictions for 2^{nd}, 3^{rd}, 4^{th}, 6^{th}, 7^{th} and 8^{th} frames use candidate motion vectors in 1^{st} and 3^{rd} frames, 1^{st} and 5^{th} frames, 3^{rd} and 5^{th} frames, 5^{th} and 7^{th} frames, 5^{th} frame and 1^{st} frame in the next GOP, 7^{th} frame and 1^{st} frame in the next GOP, respectively.

In other views, temporal prediction is performed same as the temporal prediction in the second view. Inter-view predictions for 1^{st} and 5^{th} frames in a GOP are also performed same as the inter-view predictions for 1^{st} and 5^{th} frames in a GOP in the second view. Inter-view prediction for the other frames in a GOP is performed same as the inter-view prediction for the other frames in a GOP in the second view but with additional candidate motion vectors in same, previous and future reference frames in the previous view.

To determine the amount of computation reduction achieved by the proposed algorithm and its impact on the rate distortion performance of the H.264 MVC encoder with the prediction structure shown in Fig. 1.3, we integrated the proposed algorithm to Joint multiview video coding (JMVC) 3.01 H.264 MVC software [15] and disabled its following features: determining the search window according to the predicted vector, variable block size search, sub-pixel search, multi-frame search, fast search algorithms and variable quantization parameter (QP) values. Disabling these features caused 0.55 dB PSNR loss and between 400 and 450 kbit/s bit rate increase.

The proposed vector prediction based fast motion estimation algorithm (VPBFMEA) is compared with full search motion estimation algorithm (FSMEA) with [-32, +32] search range using JMVC 3.01 H.264 MVC software for VGA (640 x 480) size Ballroom and Vassar multiview videos with eight views, 25 frames per second and 81 frames in each view [10] and for XGA (1024 x 768) size Breakdance and Uli multiview videos with eight views, 25 frames per second and 81 frames in each view [11] with quantization parameters 22, 32 and 42.

The results are given in Tables 3.1 – 3.12. In VPBFMEA version 1 (v1), [-32, +32] size search window is used for FSME. In the second view, inter-view prediction is performed with FSME with [-32, +32] size search window. In inter-view prediction, only the right side of the search window in the previous view is searched. 3 different size refinement search windows (0, [-1, +1], and [-2, +2]) are tried for this version of VPBFMEA, and the results are shown in the tables. Since the best results are obtained with refinement search window size [-2, +2], it is used in the later versions.

Cameras are linearly placed for Ballroom and Vassar multiview videos. But, this is not the case for Breakdance and Uli videos. Therefore, in VPBFMEA version 2 (v2), in inter-view prediction, searching only the right side of the search window in the previous view is not done. Since FSME has high computational complexity, in VPBFMEA version 3 (v3), in the second view, inter-view prediction except for 1st and 5th frames in a GOP is performed with VPBFME with negligible PSNR loss. Finally, in VPBFMEA version 4 (v4), search window size for FSME in 1st and 5th frames is changed from [-32, +32] to [-16, +16] to significantly reduce the amount of computation.

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	40.32	42.99	42.98	4114.09
VPBFMEA v1 with no ref.	40.33	42.99	42.98	4157.49
VPBFMEA v1 with ref. SW 1	40.31	43.00	42.98	4098.40
VPBFMEA v1 with ref. SW 2	40.31	43.00	42.98	4073.28
VPBFMEA v2	40.32	42.99	42.98	4130.19
VPBFMEA v3	40.32	42.99	42.98	4128.24
VPBFMEA v4	40.35	42.99	42.98	4217.80

Table 3.1 Average PSNR And Bit Rate Values For 8 Views Of Ballroom With QP 22

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	34.75	39.18	38.99	898.81
VPBFMEA v1 without ref.	34.74	39.12	38.95	913.74
VPBFMEA v1 with ref. SW 1	34.73	39.16	38.98	881.93
VPBFMEA v1 with ref. SW 2	34.74	39.17	38.99	869.48
VPBFMEA v2	34.75	39.15	38.98	906.25
VPBFMEA v3	34.75	39.15	38.98	905.45
VPBFMEA v4	34.76	39.11	38.94	963.52

Table 3.2 Average PSNR And Bit Rate Values For 8 Views Of Ballroom With QP 32

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	29.53	36.65	36.53	319.18
VPBFMEA v1 without ref.	29.43	36.57	36.43	299.53
VPBFMEA v1 with ref. SW 1	29.48	36.62	36.49	300.44
VPBFMEA v1 with ref. SW 2	29.50	36.66	36.53	294.67
VPBFMEA v2	29.49	36.59	36.48	312.23
VPBFMEA v3	29.49	36.60	36.48	311.69
VPBFMEA v4	29.46	36.50	36.38	330.06

Table 3.3 Average PSNR And Bit Rate Values For 8 Views Of Ballroom With QP 42

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	40.16	43.10	42.73	3526.18
VPBFMEA v1 without ref.	40.16	43.09	42.72	3537.01
VPBFMEA v1 with ref. SW 1	40.16	43.09	42.72	3525.76
VPBFMEA v1 with ref. SW 2	40.16	43.09	42.72	3524.98
VPBFMEA v2	40.16	43.09	42.73	3525.81
VPBFMEA v3	40.16	43.09	42.73	3525.70
VPBFMEA v4	40.17	43.10	42.73	3539.46

Table 3.4 Average PSNR And Bit Rate Values For 8 Views Of Vassar With QP 22

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	34.93	40.62	39.77	373.20
VPBFMEA v1 without ref.	34.92	40.61	39.77	365.11
VPBFMEA v1 with ref. SW 1	34.92	40.62	39.77	362.18
VPBFMEA v1 with ref. SW 2	34.92	40.62	39.77	363.31
VPBFMEA v2	34.92	40.61	39.77	363.63
VPBFMEA v3	34.92	40.61	39.77	362.48
VPBFMEA v4	34.92	40.59	39.76	368.03

Table 3.5 Average PSNR And Bit Rate Values For 8 Views Of Vassar With QP 32

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	30.75	39.12	38.14	142.41
VPBFMEA v1 without ref.	30.70	39.12	38.13	125.55
VPBFMEA v1 with ref. SW 1	30.72	39.13	38.13	130.26
VPBFMEA v1 with ref. SW 2	30.73	39.13	38.13	132.25
VPBFMEA v2	30.73	39.12	38.13	132.20
VPBFMEA v3	30.73	39.12	38.13	131.39
VPBFMEA v4	30.69	39.10	38.11	131.13

Table 3.6 Average PSNR And Bit Rate Values For 8 Views Of Vassar With QP 42

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	41.15	44.54	45.94	3336.24
VPBFMEA v1 without ref.	41.16	44.49	45.86	3561.51
VPBFMEA v1 with ref. SW 1	41.15	44.51	45.88	3451.11
VPBFMEA v1 with ref. SW 2	41.15	44.51	45.89	3417.54
VPBFMEA v2	41.14	44.52	45.89	3352.47
VPBFMEA v3	41.14	44.51	45.89	3354.32
VPBFMEA v4	41.16	44.50	45.87	3410.69

Table 3.7 Average PSNR And Bit Rate Values For 8 Views Of Breakdance With QP 22

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	38.26	42.19	43.27	550.05
VPBFMEA v1 without ref.	38.16	42.01	43.13	608.65
VPBFMEA v1 with ref. SW 1	38.20	42.07	43.17	583.47
VPBFMEA v1 with ref. SW 2	38.22	42.09	43.19	574.70
VPBFMEA v2	38.21	42.12	43.20	535.79
VPBFMEA v3	38.21	42.12	43.19	536.28
VPBFMEA v4	38.20	42.01	43.13	563.40

Table 3.8 Average PSNR And Bit Rate Values For 8 Views Of Breakdance With QP 32

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	35.31	39.52	40.51	282.31
VPBFMEA v1 without ref.	34.92	39.39	40.40	263.04
VPBFMEA v1 with ref. SW 1	35.08	39.44	40.43	270.18
VPBFMEA v1 with ref. SW 2	35.14	39.46	40.46	272.17
VPBFMEA v2	35.14	39.47	40.45	260.76
VPBFMEA v3	35.13	39.46	40.45	260.65
VPBFMEA v4	34.95	39.32	40.35	263.73

Table 3.9 Average PSNR And Bit Rate Values For 8 Views Of Breakdance With QP 42

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	40.65	41.30	43.72	9494.16
VPBFMEA v1 without ref.	40.66	41.29	43.70	9787.92
VPBFMEA v1 with ref. SW 1	40.65	41.30	43.72	9514.63
VPBFMEA v1 with ref. SW 2	40.65	41.30	43.72	9490.19
VPBFMEA v2	40.65	41.30	43.72	9495.29
VPBFMEA v3	40.65	41.30	43.72	9495.12
VPBFMEA v4	40.66	41.30	43.72	9504.88

Table 3.10 Average PSNR And Bit Rate Values For 8 Views Of Uli With QP 22

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	35.78	37.31	39.08	2426.91
VPBFMEA v1 without ref.	35.75	37.28	39.05	2525.43
VPBFMEA v1 with ref. SW 1	35.76	37.31	39.07	2424.02
VPBFMEA v1 with ref. SW 2	35.77	37.31	39.07	2414.62
VPBFMEA v2	35.77	37.31	39.08	2422.57
VPBFMEA v3	35.77	37.31	39.08	2422.33
VPBFMEA v4	35.80	37.31	39.05	2431.90

Table 3.11 Average PSNR And Bit Rate Values For 8 Views Of Uli With QP 32

	Y	U	V	Bit Rate
FSMEA [-32, +32] SW	30.32	34.86	36.46	753.95
VPBFMEA v1 without ref.	30.17	34.82	36.44	725.70
VPBFMEA v1 with ref. SW 1	30.25	34.85	36.45	719.94
VPBFMEA v1 with ref. SW 2	30.26	34.86	36.46	723.98
VPBFMEA v2	30.29	34.84	36.45	727.16
VPBFMEA v3	30.29	34.84	36.45	726.41
VPBFMEA v4	30.32	34.81	36.40	723.68

Table 3.12 Average PSNR And Bit Rate Values For 8 Views Of Uli With QP 42

The rate distortion curves obtained by using average Y PSNR and bitrate values from the above tables are shown below. PSNR values are shown in Y axis and bitrate values are shown in X axis. As expected, the best coding quality is obtained by FSMEA and worst coding quality is obtained by VPBFMEA version 1 with no refinement. All algorithms perform similarly for Vassar, because there is very low motion. As refinement search window size is increased, coding quality is increased as expected. VPBFMEA version 4 has similar coding quality with FSMEA and it has much less computational complexity.

Computation comparisons of these algorithms are shown in Fig. 3.7 and Fig. 3.8.

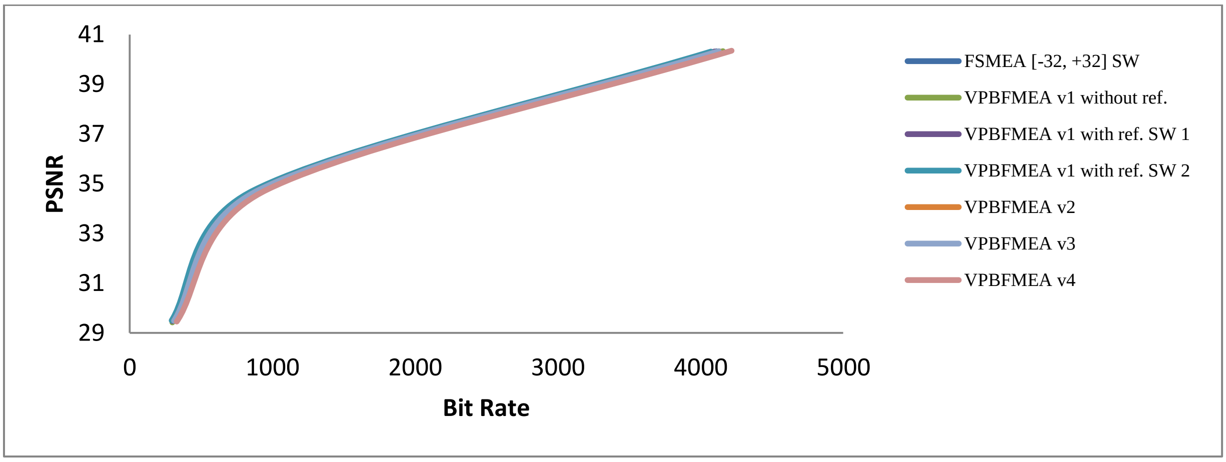

Figure 3.3 Rate-Distortion Curves For Ballroom

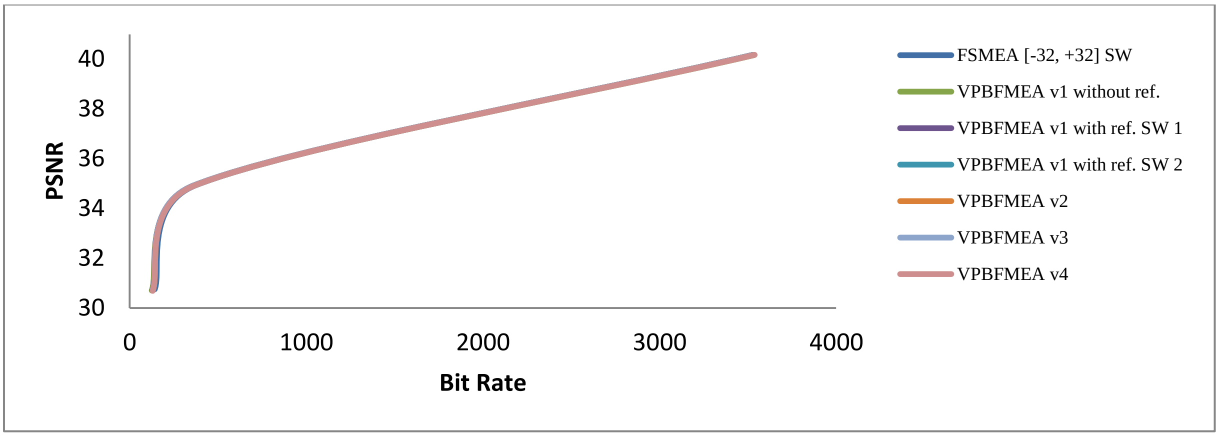

Figure 3.4 Rate-Distortion Curves For Vassar

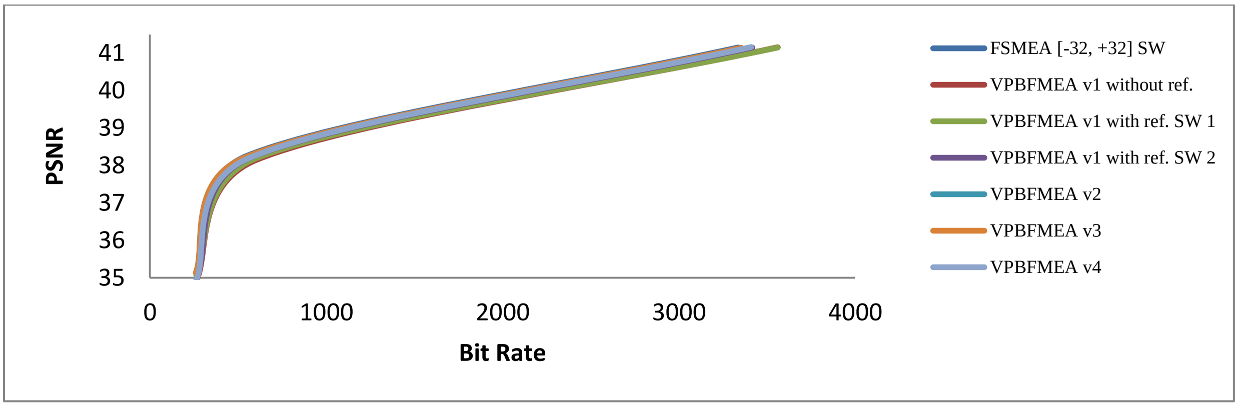

Figure 3.5 Rate-Distortion Curves For Breakdance

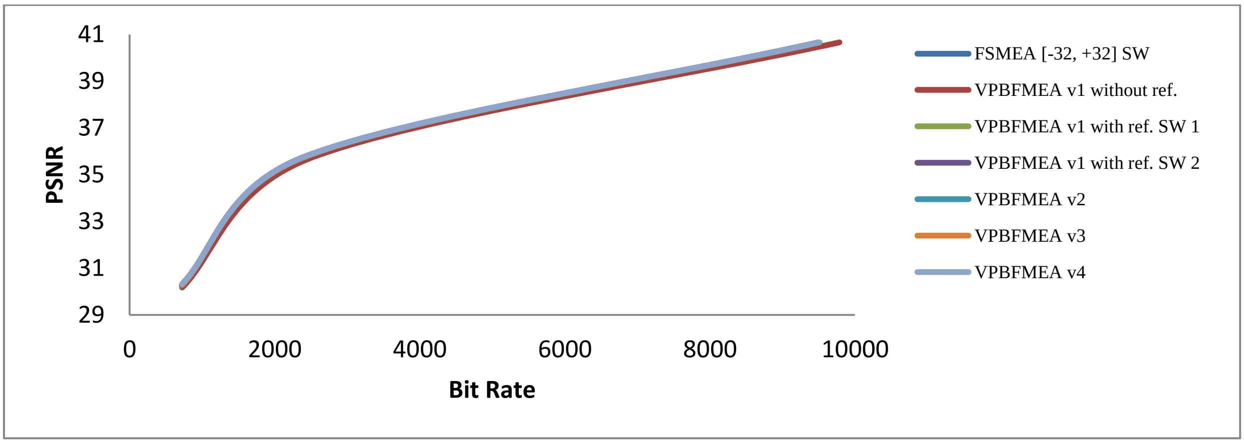

Figure 3.6 Rate-Distortion Curves For Uli

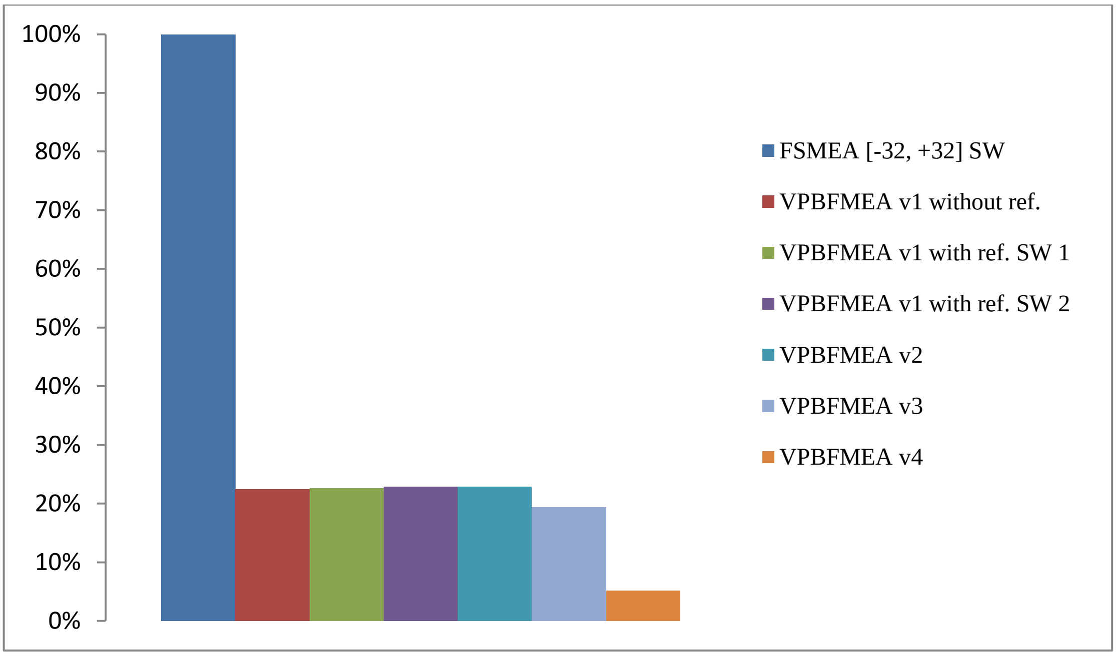

Figure 3.7 Computation Comparison For Ballroom And Vassar

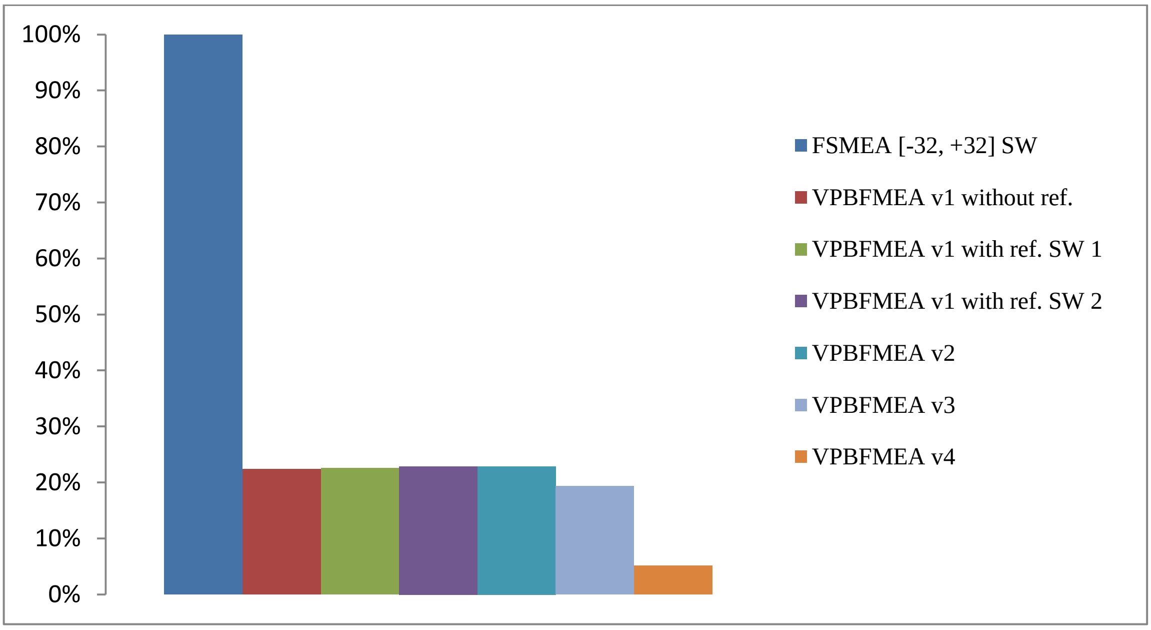

Figure 3.8 Computation Comparison For Breakdance And Uli

3.2 Vector Prediction Based Fast Motion Estimation Hardware

We also proposed a vector prediction based fast motion estimation hardware. As shown in Fig. 3.9, the proposed hardware consists of three modules working in parallel. LR module performs left temporal prediction, RR module performs right temporal prediction and IR module performs inter-view prediction. As shown in Fig. 3.10, each module has two parts. The first part has datapath, control unit and on-chip memory for implementing FSME. The second part has datapath, control unit and on-chip memory for implementing VPBFME. Since these two parts do not work at the same time, they share 256 PEs, adder tree and comparator shown in Fig. 3.11.

VPBFME part first reads current MB data from off-chip memory and stores it into 16x16 PE array. Then, it reads reference MB data for the candidate motion vector from off-chip memory and stores it into PE array in 16 clock cycles. Then, it calculates SAD value. AD calculation takes 1 clock cycle and adder tree takes 4 clock cycles. SAD value is calculated in 5 clock cycles. While it is calculating the SAD value for the current candidate motion vector, it reads reference MB data for the next candidate motion vector from off-chip memory and stores it into PE array. If the calculated SAD value is smaller than the minimum SAD value, minimum SAD value and best motion vector are replaced with this SAD value and candidate motion vector, respectively.

After SAD values for all candidate motion vectors are calculated, it searches [-2, +2] search window around the best motion vector. It reads the search window data from off-chip memory in 20 clock cycles and stores it into registers. In each clock cycle, it reads 20 bytes. After first 16 clock cycles, it starts calculating SAD values for search locations. Therefore, SAD values for 25 search locations are calculated in 45 clock cycles.

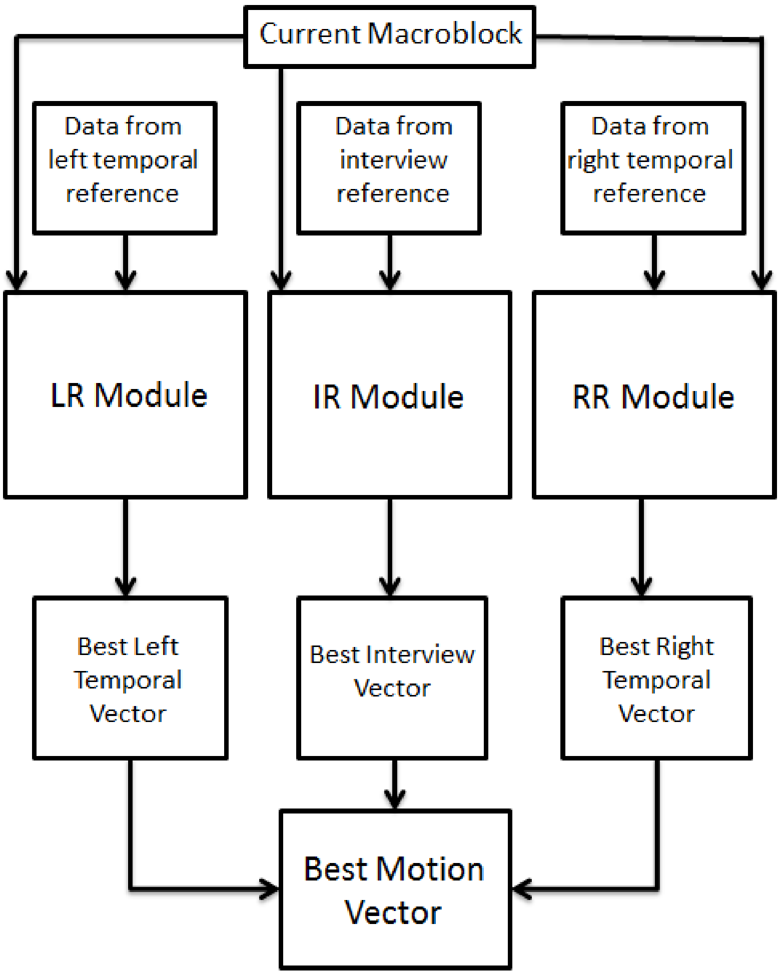

Figure 3.9 H.264 MVC VPBFME Hardware

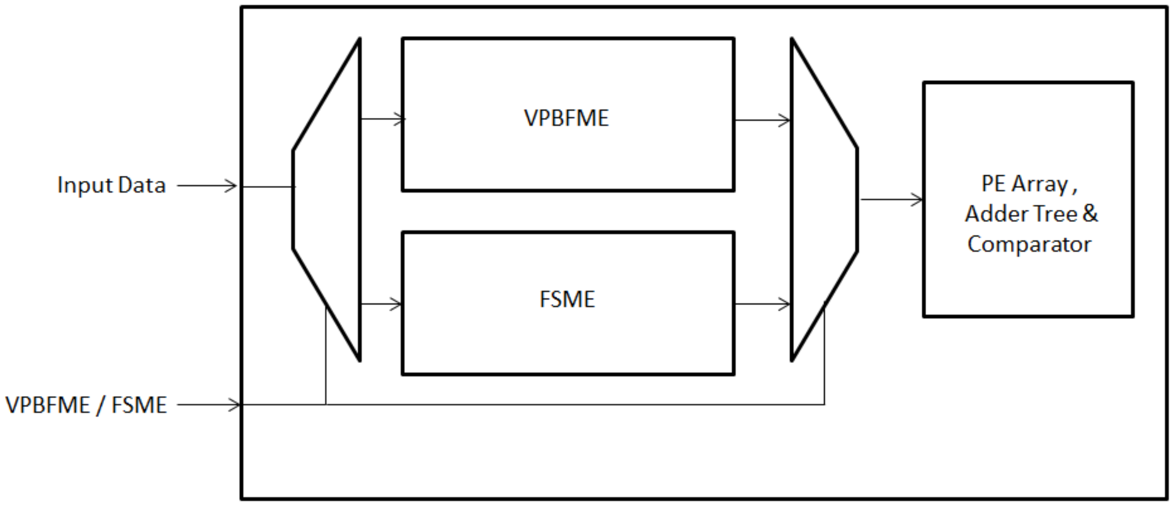

Figure 3.10 Prediction Module

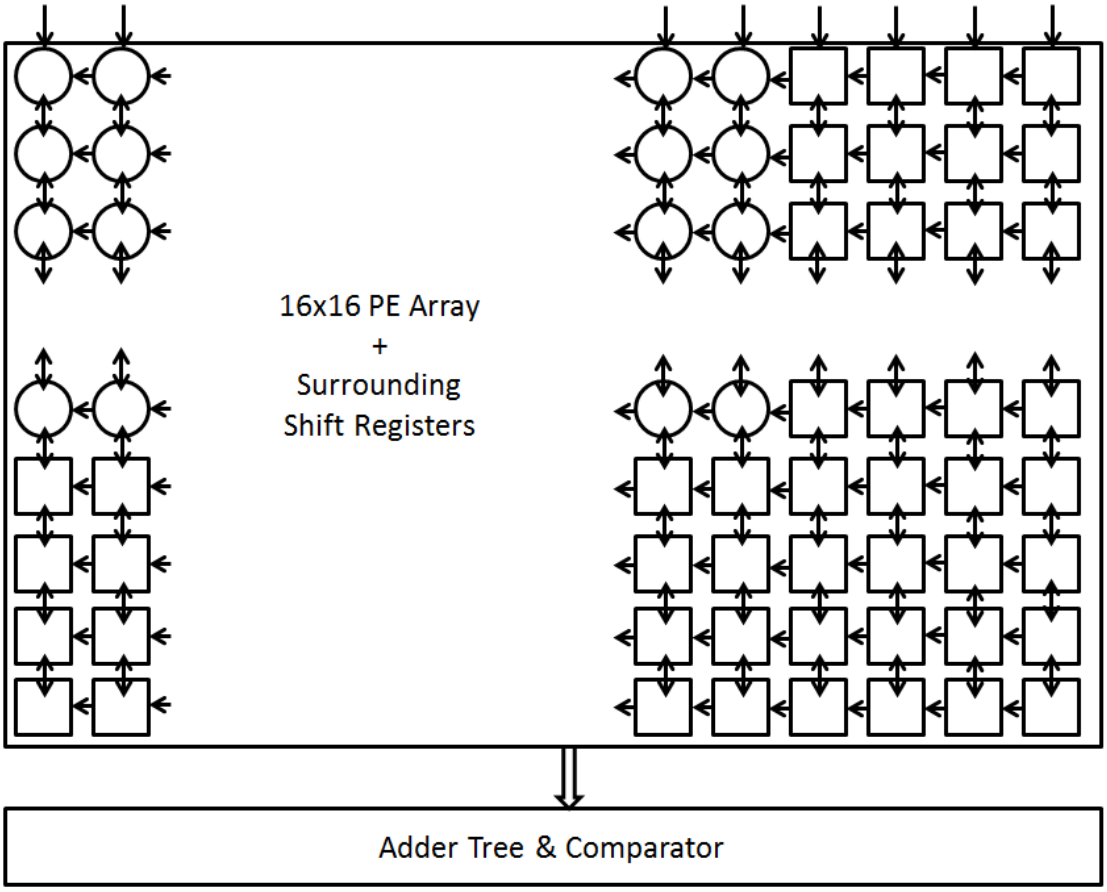

Figure 3.11 256 PE Array And Surrounding Shift Registers

The proposed VPBFME hardware is implemented using Verilog HDL. The Verilog RTL codes are mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 13.4. The FPGA implementation is verified with post place & route simulations using Mentor Graphics ModelSim 10.4a. It consumes 22942 slices, 60596 LUTs, 51942 DFFs and 36 BRAMs, and it works at 76 MHz.

The timing results of the FPGA implementation for VGA size multiview video are shown in Table 3.13. Since the first frame in a GOP in the first view is intra coded, it is not taken into consideration. The FPGA implementation processes the first view (performs temporal predictions) in 4*4 + 6.2*2 + 16.75 = 45.15ms. It processes the second view (performs temporal and inter-view predictions) in 8.4*4 + 12.7*2 + 16.75*2 = 92.5ms. It processes the other views in 12.7*6 + 16.75*2 = 109.7ms. Since the FPGA implementation processes three views in 45.15+92.5+109.7 = 247.35ms, it is capable of processing 92 frames per second of VGA size three view video sequence.

	Frame1	Frame2	Frame3	Frame4	Frame5	Frame6	Frame7	Frame8	GOP Total
View1	0	4	4	6.2	16.75	6.2	4	4	45.15
View2	16.75	8.4	8.4	12.7	16.75	12.7	8.4	8.4	92.5
View3	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7
View4	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7
View5	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7
View6	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7
View7	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7
View8	16.75	12.7	12.7	12.7	16.75	12.7	12.7	12.7	109.7

Table 3.13 Timing Results For VGA Size Multiview Video

We estimated the power consumption of the proposed VPBFME hardware on the same FPGA using Xilinx XPower tool for one frame of VGA (640x480) size Ballroom multiview video. In order to estimate its power consumption, timing simulation of placed & routed netlist of the proposed VPBFME hardware is done at 76 MHz using Mentor Graphics ModelSim SE for the second frame in third view of first GOP in Ballroom multiview video. The signal activities of this timing simulation are stored in a VCD file, and this VCD file is used for estimating the power consumption using Xilinx XPower tool. The power and energy consumption results are shown in Table 3.14. The results show that the proposed VPBFME hardware consumes 66% less energy than H.264 MVC full search motion estimation hardware including the novel energy reduction techniques [12], [16], and it consumes 91% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques.

	Average Power (mW)	**Time (μs)**	**Energy (mj)**	**Energy Reduction (%)**
Full Search ME Hardware Without Novel Techniques	1489.62	41600	61.9	0
Full Search ME Hardware With Novel Techniques	1529.82	11600	17.7	71
VPBFME Hardware	465	12700	5.9	91

Table 3.14 Power and Energy Consumption Results For One Frame

Chapter 4

CONCLUSION AND FUTURE WORK

In this thesis, we proposed an H.264 MVC full search motion estimation hardware for implementing the temporal and inter-view predictions including several novel energy reduction techniques [12], [16]. The proposed H.264 MVC motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 11.5. The FPGA implementation consumes 13303 slices, 40598 LUTs, 22024 DFFs and 60 BRAMs, and works at 125 MHz. The FPGA implementation is capable of processing 30*8=240 frames per second of CIF (352x288) size 8 view video sequence or 30*2=60 frames per second of VGA (640x480) size stereo (2 views) video sequence. It consumes 65% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

We also proposed a vector prediction based fast motion estimation algorithm for reducing the energy consumption of H.264 MVC motion estimation hardware by utilizing the correlation between motion vectors of neighboring macro blocks with additional very small PSNR loss and bitrate increase. We also proposed an H.264 MVC motion estimation hardware for implementing the proposed fast motion estimation algorithm. The proposed motion estimation hardware is implemented in Verilog HDL and mapped to a Xilinx Virtex-6 XC6VLX760 FPGA with package FF1760 and speed grade -2 using Xilinx ISE 13.4. The FPGA implementation consumes 22942 slices, 60596 LUTs, 51942 DFFs and 36 BRAMs, and works at 76 MHz. The FPGA implementation is capable of processing 92 frames per second of VGA size three view video sequence. It consumes 91% less energy than H.264 MVC full search motion estimation hardware not including the novel energy reduction techniques with very small PSNR loss and bitrate increase.

As future work, the proposed vector prediction based fast motion estimation algorithm can be improved to further reduce its computational complexity. For example, SAD calculation for identical candidate motion vectors can be avoided. SAD calculation for similar candidate motion vectors can be avoided at the cost of additional minor quality loss. The number of candidate vectors and the refinement range can be determined dynamically. The proposed vector prediction based fast motion estimation hardware can also be improved to increase its performance and reduce its energy consumption. For example, on-chip search window memory can be used for storing the search windows of identical or similar candidate motion vectors so that their SAD calculations can be done without waiting for 16 clock cycles to load each reference macro block separately. The clock frequency can be increased by further pipelining.

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APPENDIX A. DETAILED EXPERIMENTAL RESULTS

QP 22				
View	Y	U	V	Bit Rate
0	40.5908	43.0828	43.1429	4214.104
1	40.2714	42.8523	42.8795	4248.291
2	40.4019	43.1972	43.2225	3835.657
3	40.2994	43.0148	42.9944	3921.425
4	40.2524	42.9373	42.8244	4112.911
5	40.5603	43.4211	43.333	3667.447
6	40.0351	42.6774	42.7842	4650.343
7	40.1792	42.7754	42.6786	4262.536
Average	**40.32381**	**42.99479**	**42.98244**	**4114.089**

Table A.1 Results For Ballroom Using FSMEA With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9091	39.0505	38.9799	1085.548
1	34.8697	39.2477	38.9714	885.1259
2	35.0248	39.6033	39.4622	811.3111
3	34.6227	39.1018	39.0063	859.7383
4	34.6041	39.0578	38.76	895.4691
5	35.026	39.4145	39.3025	863.4593
6	34.5895	39.2178	39.0457	863.8642
7	34.3466	38.7403	38.3786	925.9951
Average	**34.74906**	**39.17921**	**38.98833**	**898.8139**

Table A.2 Results For Ballroom Using FSMEA With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.6039	36.4826	36.4201	351.5383
1	29.588	36.7625	36.4528	313.9951
2	29.9706	37.1974	37.0133	301.6074
3	29.3806	36.6585	36.6341	309.3778
4	29.3271	36.7338	36.401	314.3333
5	29.7899	36.6302	36.6659	318.5062
6	29.7101	36.5379	36.5634	314.8296
7	28.8852	36.199	36.0515	329.2444
Average	**29.53193**	**36.65024**	**36.52526**	**319.179**

Table A.3 Results For Ballroom Using FSMEA With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0934	42.8805	42.5776	3661.459
1	40.038	42.8649	42.4293	3857.79
2	40.2635	43.291	42.8038	3407.654
3	40.1247	43.1488	42.9495	3374.795
4	40.0597	42.9858	42.7289	3359.536
5	40.6048	43.9921	43.5246	2613.543
6	39.9825	42.6922	42.2233	4485.222
7	40.1369	42.9057	42.5694	3449.435
Average	**40.16294**	**43.09513**	**42.7258**	**3526.179**

Table A.4 Results For Vassar Using FSMEA With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9242	40.1874	39.463	420.3383
1	34.8577	40.3729	39.3387	361.9778
2	35.1625	40.9894	39.822	346.4099
3	34.9312	40.667	40.2467	355.316
4	34.7491	40.3358	39.6508	348.8593
5	35.4929	41.7059	40.8329	325.5926
6	34.6046	40.4058	39.2019	424.2765
7	34.6983	40.2846	39.6397	402.8222
Average	**34.92756**	**40.6186**	**39.77446**	**373.1991**

Table A.5 Results For Vassar Using FSMEA With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.8081	38.4253	37.5328	132.284
1	30.7683	38.8793	37.5522	141.4346
2	31.1307	39.4403	38.0687	137.5802
3	30.7918	39.2524	38.7387	139.4123
4	30.6825	39.0247	37.9108	141.7457
5	31.1911	40.0817	39.2981	149.3926
6	30.4269	39.0659	37.7273	148.2222
7	30.197	38.8297	38.2561	149.242
Average	**30.74955**	**39.12491**	**38.13559**	**142.4142**

Table A.6 Results For Vassar Using FSMEA With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9238	44.2029	45.3661	4175.09
1	41.245	44.8047	45.698	3269.699
2	41.1006	44.6246	45.7354	3206.28
3	41.263	44.5987	46.5225	3081.538
4	41.2491	44.5198	46.4156	3134.733
5	41.1815	44.6444	45.8897	3268.92
6	41.066	44.4827	46.0292	3162.982
7	41.1679	44.404	45.8954	3390.705
Average	**41.14961**	**44.53523**	**45.94399**	**3336.244**

Table A.7 Results For Breakdance Using FSMEA With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.9274	41.6567	42.4281	720.7615
1	38.2153	42.2924	42.957	560.2741
2	38.3344	42.3752	43.0466	495.7511
3	38.243	42.1709	43.7988	551.2785
4	38.5751	42.4933	43.9806	498.0163
5	38.1287	42.3102	43.083	539.5985
6	38.2957	42.0967	43.5473	508.9215
7	38.3284	42.0915	43.3061	525.8311
Average	**38.256**	**42.18586**	**43.26844**	**550.0541**

Table A.8 Results For Breakdance Using FSMEA With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.8332	38.8529	39.7569	297.7467
1	34.8932	39.3922	40.1283	295.5704
2	35.5174	39.6985	40.373	276.0993
3	34.9991	39.4877	40.7118	280.8237
4	36.0906	40.1218	41.0091	267.7096
5	35.099	39.867	40.3015	284.7719
6	35.4038	39.4029	40.899	279.6474
7	35.6464	39.3553	40.8634	276.1393
Average	**35.31034**	**39.52229**	**40.50538**	**282.3135**

Table A.9 Results For Breakdance Using FSMEA With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2777	40.2077	43.4104	11554.61
1	40.2014	40.7205	42.6526	12442.55
2	40.6454	40.9399	43.6609	9801.203
3	39.9688	41.2178	43.3171	11671.55
4	41.1767	41.7286	44.3926	7574.012
5	41.1525	42.156	44.2723	6871.22
6	41.0435	41.823	44.9386	7003.696
7	40.7506	41.6019	43.1482	9034.44
Average	**40.65208**	**41.29943**	**43.72409**	**9494.159**

Table A.10 Results For Uli Using FSMEA With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9251	35.3915	39.0686	3101.257
1	34.5973	36.204	37.6793	3273.094
2	35.6383	37.0655	39.1424	2540.464
3	35.2053	37.5871	38.6152	2647.133
4	36.5973	37.9004	39.9964	1967.943
5	36.819	38.8732	39.5134	1755.432
6	36.7265	38.0656	40.5328	1787.882
7	35.7086	37.4274	38.106	2342.044
Average	**35.77718**	**37.31434**	**39.08176**	**2426.906**

Table A.11 Results For Uli Using FSMEA With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.2184	32.5464	36.5242	909.8469
1	28.688	33.6165	35.0599	928.0123
2	30.0978	34.83	36.589	796.1704
3	29.8546	35.2682	35.998	751.9951
4	31.3813	35.3687	37.4414	659.5728
5	31.6532	36.8097	36.7453	620.7901
6	31.5086	35.5821	37.9606	633.2469
7	30.1321	34.8432	35.3466	731.9309
Average	**30.31675**	**34.8581**	**36.45813**	**753.9457**

Table A.12 Results For Uli Using FSMEA With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.6125	43.0783	43.1449	4349.874
1	40.2781	42.8424	42.8711	4242.496
2	40.4083	43.1938	43.2203	3892.919
3	40.2985	43.012	42.9896	3961.227
4	40.2487	42.9344	42.8233	4131.296
5	40.5521	43.411	43.3252	3691.003
6	40.0407	42.6779	42.7846	4675.254
7	40.1757	42.7799	42.6734	4315.815
Average	**40.32683**	**42.99121**	**42.97905**	**4157.486**

Table A.13 Results For Ballroom Using VPBFMEA Version 1 With No Refinement And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9247	38.9706	38.9279	1171.501
1	34.8555	39.1981	38.9307	871.4049
2	35.0125	39.551	39.4214	823.9506
3	34.6126	39.023	38.9743	866.8914
4	34.5838	38.9878	38.7358	897.763
5	35.0069	39.355	39.266	864.1926
6	34.5727	39.1859	39.0249	869.9407
7	34.3411	38.694	38.3379	944.2691
Average	**34.73873**	**39.12068**	**38.95236**	**913.7392**

Table A.14 Results For Ballroom Using VPBFMEA Version 1 With No Refinement And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5352	36.3204	36.2923	369.2198
1	29.5287	36.6589	36.3519	299.2889
2	29.8557	37.1322	36.8973	275.6889
3	29.2729	36.6014	36.5617	282.6198
4	29.2073	36.6602	36.3209	287.4963
5	29.6492	36.5671	36.5985	288.8469
6	29.5797	36.4419	36.4542	288.4765
7	28.7818	36.151	35.9723	304.5679
Average	**29.42631**	**36.56664**	**36.43114**	**299.5256**

Table A.15 Results For Ballroom Using VPBFMEA Version 1 With No Refinement And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0948	42.8806	42.5771	3670.091
1	40.0396	42.8647	42.4234	3861.938
2	40.2652	43.289	42.7975	3416.286
3	40.1248	43.1468	42.9475	3386.721
4	40.0624	42.9842	42.7297	3376.494
5	40.5983	43.9893	43.5148	2623.106
6	39.9816	42.6885	42.2197	4492.358
7	40.1352	42.9068	42.5688	3469.111
Average	**40.16274**	**43.09374**	**42.72231**	**3537.013**

Table A.16 Results For Vassar Using VPBFMEA Version 1 With No Refinement And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9216	40.1796	39.4559	425.7333
1	34.8488	40.3608	39.3256	356.2889
2	35.1487	40.9786	39.8098	329.1012
3	34.9158	40.6608	40.2452	343.5753
4	34.7318	40.3253	39.6532	337.8741
5	35.4802	41.6998	40.8314	311.9728
6	34.5979	40.4044	39.1827	413.8123
7	34.6877	40.302	39.6297	402.5556
Average	**34.91656**	**40.61391**	**39.76669**	**365.1142**

Table A.17 Results For Vassar Using VPBFMEA Version 1 With No Refinement And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7855	38.4131	37.5242	129.1531
1	30.7579	38.8791	37.5434	138.1358
2	31.0848	39.4297	38.048	117.679
3	30.7411	39.2547	38.739	117.7185
4	30.6239	39.0166	37.9126	121.6049
5	31.1177	40.1078	39.2671	124.6691
6	30.3729	39.0459	37.7315	126.9136
7	30.1334	38.845	38.2429	128.5457
Average	**30.70215**	**39.12399**	**38.12609**	**125.5525**

Table A.18 Results For Vassar Using VPBFMEA Version 1 With No Refinement And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9305	44.174	45.2812	4367.882
1	41.2485	44.7684	45.6418	3507.381
2	41.1001	44.5693	45.6429	3441.159
3	41.2671	44.5525	46.4532	3364.284
4	41.2571	44.4589	46.3347	3318.239
5	41.1883	44.6063	45.8236	3532.75
6	41.0703	44.4314	45.9404	3372.744
7	41.1868	44.3592	45.8007	3587.676
Average	**41.15609**	**44.49**	**45.86481**	**3561.514**

Table A.19 Results For Breakdance Using VPBFMEA Version 1 With No Refinement And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8324	41.5169	42.2828	757.2148
1	38.1411	42.1495	42.8283	648.3452
2	38.1958	42.2115	42.8809	531.9452
3	38.1356	41.9763	43.6392	623.1185
4	38.4609	42.2761	43.8235	543.1378
5	38.0456	42.1124	42.9462	612.5689
6	38.2165	41.95	43.4439	568.6326
7	38.2458	41.9021	43.1591	584.197
Average	**38.15921**	**42.01185**	**43.12549**	**608.645**

Table A.20 Results For Breakdance Using VPBFMEA Version 1 With No Refinement And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.4397	38.7084	39.6208	268.0296
1	34.7044	39.2543	40.0381	302.5126
2	35.1242	39.6039	40.2917	242.5496
3	34.6452	39.3497	40.6111	260.1141
4	35.5784	39.9208	40.8625	248.0993
5	34.725	39.7038	40.2273	269.8919
6	35.0013	39.2995	40.7928	259.6904
7	35.1504	39.2597	40.7345	253.4178
Average	**34.92108**	**39.38751**	**40.39735**	**263.0382**

Table A.21 Results For Breakdance Using VPBFMEA Version 1 With No Refinement And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2842	40.1894	43.3691	12135.04
1	40.2058	40.7055	42.6356	12747.33
2	40.6507	40.9253	43.6434	10122.38
3	39.9743	41.2093	43.3037	11956.2
4	41.181	41.7174	44.3613	7839.978
5	41.1622	42.1493	44.239	7074.277
6	41.0436	41.8119	44.9188	7180.032
7	40.761	41.5912	43.1374	9248.131
Average	**40.65785**	**41.28741**	**43.70104**	**9787.92**

Table A.22 Results For Uli Using VPBFMEA Version 1 With No Refinement And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.887	35.3514	39.022	3334.548
1	34.5777	36.1727	37.6593	3386.168
2	35.5984	37.0146	39.11	2653.98
3	35.1802	37.5563	38.5818	2745.079
4	36.556	37.8577	39.9459	2058.077
5	36.8003	38.8593	39.4696	1808.104
6	36.6852	38.02	40.5155	1824.195
7	35.6771	37.4103	38.0752	2393.286
Average	**35.74524**	**37.28029**	**39.04741**	**2525.43**

Table A.23 Results For Uli Using VPBFMEA Version 1 With No Refinement And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.0577	32.4897	36.4973	914.1827
1	28.595	33.5978	35.0085	928.8444
2	29.9175	34.7737	36.5776	760.8914
3	29.7188	35.2549	35.9566	721.2568
4	31.1848	35.3172	37.4141	628.2914
5	31.5116	36.8015	36.7407	576.2123
6	31.3658	35.5314	37.9697	591.9827
7	30.0216	34.8269	35.3469	683.9111
Average	**30.1716**	**34.82414**	**36.43893**	**725.6966**

Table A.24 Results For Uli Using VPBFMEA Version 1 With No Refinement And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.6007	43.0805	43.1449	4306.415
1	40.2691	42.8481	42.8766	4215.983
2	40.3954	43.1998	43.2247	3827.459
3	40.2868	43.0177	42.9935	3892.63
4	40.2374	42.9417	42.8298	4063.153
5	40.5387	43.4232	43.337	3625.778
6	40.0281	42.6845	42.7863	4615.311
7	40.1616	42.7876	42.6776	4240.489
Average	**40.31473**	**42.99789**	**42.9838**	**4098.402**

Table A.25 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 1 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.913	38.9995	38.947	1139.677
1	34.8544	39.2266	38.9532	855.6296
2	35.0092	39.5887	39.4555	790.3531
3	34.609	39.0575	39.0066	833.0099
4	34.5834	39.0276	38.7653	864.7679
5	35.0018	39.4006	39.3065	829.9235
6	34.567	39.2239	39.0556	835.6148
7	34.3346	38.7253	38.3755	906.4642
Average	**34.73405**	**39.15621**	**38.98315**	**881.9299**

Table A.26 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 1 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5475	36.3652	36.3274	360.2617
1	29.5495	36.7104	36.3932	297.2815
2	29.9214	37.1924	36.9611	278.6543
3	29.332	36.6429	36.6266	286.1037
4	29.2664	36.7297	36.3886	290.6963
5	29.7192	36.6139	36.6789	292.8889
6	29.6421	36.5183	36.5313	291.4222
7	28.8356	36.2123	36.05	306.2173
Average	**29.47671**	**36.62314**	**36.49464**	**300.4407**

Table A.27 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 1 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0935	42.881	42.5768	3666.035
1	40.039	42.8655	42.4235	3856.909
2	40.2633	43.2889	42.7983	3407.309
3	40.1244	43.1472	42.9486	3373.743
4	40.062	42.9848	42.7299	3361.304
5	40.5996	43.9907	43.517	2611.672
6	39.98	42.689	42.2213	4478.173
7	40.1348	42.9066	42.5712	3450.965
Average	**40.16208**	**43.09421**	**42.72333**	**3525.764**

Table A.28 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 1 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9217	40.1829	39.4591	421.3284
1	34.8514	40.363	39.3299	354.7481
2	35.1528	40.9848	39.8161	330.0519
3	34.9184	40.6616	40.2484	340.5284
4	34.7353	40.3294	39.6541	335.279
5	35.4834	41.7042	40.8374	311.358
6	34.6026	40.4055	39.1862	409.4099
7	34.6886	40.3043	39.6345	394.7235
Average	**34.91928**	**40.61696**	**39.77071**	**362.1784**

Table A.29 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 1 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7958	38.4147	37.5257	129.0247
1	30.7645	38.8809	37.5446	138.6025
2	31.1131	39.4362	38.0473	125.8444
3	30.7642	39.2568	38.7469	122.884
4	30.6518	39.0216	37.9137	128.6889
5	31.1501	40.1088	39.2755	131.9037
6	30.3954	39.0495	37.7355	131.8716
7	30.1579	38.8445	38.249	133.242
Average	**30.7241**	**39.12663**	**38.12978**	**130.2577**

Table A.30 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 1 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9219	44.1876	45.3037	4246.591
1	41.2433	44.7805	45.6573	3451.999
2	41.0933	44.5911	45.6636	3287.477
3	41.2629	44.5661	46.47	3238.322
4	41.2498	44.4812	46.3585	3227.562
5	41.1827	44.6183	45.8341	3414.342
6	41.062	44.4485	45.9624	3247.89
7	41.1794	44.3757	45.8211	3494.68
Average	**41.14941**	**44.50613**	**45.88384**	**3451.108**

Table A.31 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 1 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8673	41.5704	42.3236	720.6637
1	38.1791	42.1959	42.8628	639.1822
2	38.2507	42.2865	42.9374	496.9867
3	38.1828	42.0358	43.6758	596.0637
4	38.5129	42.3453	43.872	524.5689
5	38.0878	42.1745	42.9711	587.3941
6	38.263	42.0051	43.5063	540.7452
7	38.2863	41.9516	43.2085	562.1719
Average	**38.20374**	**42.07064**	**43.16969**	**583.4721**

Table A.32 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 1 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.5781	38.7638	39.6613	269.9407
1	34.7844	39.2968	40.0679	304.4548
2	35.3056	39.6661	40.3301	250.7793
3	34.793	39.3995	40.6381	268.0296
4	35.7626	39.989	40.8973	258.9289
5	34.8716	39.7665	40.2493	279.7096
6	35.1753	39.3394	40.8371	267.0785
7	35.3315	39.2936	40.7837	262.5022
Average	**35.07526**	**39.43934**	**40.4331**	**270.178**

Table A.33 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 1 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2763	40.2067	43.4048	11615.6
1	40.1988	40.7161	42.6477	12447.14
2	40.645	40.9376	43.6623	9829.852
3	39.9657	41.2207	43.3171	11674.12
4	41.1749	41.7303	44.3814	7601.091
5	41.1565	42.1596	44.2637	6889.005
6	41.0394	41.8218	44.9407	7004.262
7	40.7564	41.5974	43.1475	9055.99
Average	**40.65163**	**41.29878**	**43.72065**	**9514.632**

Table A.34 Results For Uli Using VPBFMEA Version 1 With Refinement SW 1 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9195	35.3853	39.0574	3128.551
1	34.5868	36.1947	37.6783	3264.4
2	35.6141	37.041	39.1334	2543.279
3	35.1924	37.5825	38.5963	2637.565
4	36.58	37.8876	39.9662	1974.81
5	36.8202	38.8906	39.4926	1749.437
6	36.7062	38.0405	40.5433	1767.995
7	35.6923	37.4299	38.094	2326.119
Average	**35.76394**	**37.30651**	**39.07019**	**2424.019**

Table A.35 Results For Uli Using VPBFMEA Version 1 With Refinement SW 1 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.1794	32.5244	36.512	891.1259
1	28.65	33.6295	35.0234	908.1012
2	30.0018	34.8027	36.5938	758.8691
3	29.7861	35.2854	35.964	714.8346
4	31.2737	35.3507	37.4323	628.5407
5	31.5922	36.8335	36.7539	579.758
6	31.4414	35.5537	37.9862	594.7358
7	30.0705	34.843	35.3622	683.5284
Average	**30.24939**	**34.85286**	**36.45348**	**719.9367**

Table A.36 Results For Uli Using VPBFMEA Version 1 With Refinement SW 1 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.5981	43.08	43.1443	4277.452
1	40.266	42.8481	42.8779	4201.585
2	40.3936	43.2001	43.2245	3806.753
3	40.2833	43.0203	42.9948	3864.64
4	40.2347	42.9426	42.8295	4036.948
5	40.5346	43.4233	43.3402	3597.82
6	40.0238	42.6822	42.7888	4588.314
7	40.158	42.7885	42.6781	4212.719
Average	**40.31151**	**42.99814**	**42.98476**	**4073.279**

Table A.37 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 2 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9115	39.0112	38.9561	1120.699
1	34.8548	39.2377	38.9627	849.6691
2	35.0095	39.603	39.4663	780.3802
3	34.612	39.0691	39.0179	821.2815
4	34.586	39.0411	38.773	852.442
5	35.0043	39.4191	39.3229	817.2815
6	34.568	39.2398	39.0672	821.9728
7	34.3357	38.7346	38.3864	892.0914
Average	**34.73523**	**39.16945**	**38.99406**	**869.4772**

Table A.38 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 2 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5599	36.3926	36.3471	354.8148
1	29.5658	36.7209	36.4175	296.479
2	29.9401	37.2221	36.9894	278.1086
3	29.3497	36.6732	36.6563	285.0247
4	29.2853	36.7573	36.4166	289.6346
5	29.7374	36.6379	36.7113	291.3827
6	29.6684	36.5388	36.5567	291.2
7	28.8576	36.2351	36.072	305.0025
Average	**29.50315**	**36.65935**	**36.52858**	**294.6682**

Table A.39 Results For Ballroom Using VPBFMEA Version 1 With Refinement SW 2 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0934	42.8809	42.5769	3663.968
1	40.039	42.865	42.4239	3856.741
2	40.2636	43.2892	42.7977	3407.119
3	40.1248	43.1475	42.9488	3373.565
4	40.062	42.9846	42.7303	3360.099
5	40.5999	43.9916	43.517	2611.403
6	39.9798	42.689	42.2211	4477.696
7	40.1346	42.907	42.5712	3449.212
Average	**40.16214**	**43.09435**	**42.72336**	**3524.975**

Table A.40 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 2 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9222	40.1843	39.4598	419.916
1	34.8521	40.3642	39.3312	354.8222
2	35.1545	40.9853	39.8163	332.6691
3	34.9202	40.6618	40.25	342.6173
4	34.7368	40.3303	39.6561	337.0049
5	35.4846	41.7054	40.84	313.0741
6	34.6036	40.4056	39.1873	410.6642
7	34.6898	40.3051	39.6353	395.684
Average	**34.92048**	**40.61775**	**39.772**	**363.3065**

Table A.41 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 2 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7995	38.4162	37.5277	129.116
1	30.7686	38.8825	37.5458	138.9457
2	31.1189	39.4406	38.0492	128.2321
3	30.7702	39.2592	38.7483	125.0444
4	30.6576	39.0214	37.9151	131.4099
5	31.1559	40.1083	39.2759	135.2938
6	30.4007	39.0505	37.7355	134.2519
7	30.1633	38.8459	38.2498	135.7333
Average	**30.72934**	**39.12808**	**38.13091**	**132.2534**

Table A.42 Results For Vassar Using VPBFMEA Version 1 With Refinement SW 2 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9203	44.1888	45.3058	4216.93
1	41.2439	44.7843	45.6622	3437.917
2	41.0941	44.5969	45.6728	3251.23
3	41.2616	44.5707	46.4769	3184.462
4	41.2491	44.4868	46.366	3199.914
5	41.1815	44.6198	45.8402	3375.64
6	41.0612	44.4504	45.9673	3207.877
7	41.179	44.3778	45.8314	3466.319
Average	**41.14884**	**44.50944**	**45.89033**	**3417.536**

Table A.43 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 2 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8827	41.5855	42.3408	715.0726
1	38.1901	42.2066	42.8744	637.3393
2	38.2746	42.306	42.9524	492.1896
3	38.1962	42.0625	43.7039	575.9837
4	38.5286	42.3762	43.8942	518.9304
5	38.1005	42.2034	42.9885	577.5437
6	38.2785	42.0256	43.5231	529.7363
7	38.2989	41.9746	43.2309	550.7733
Average	**38.21876**	**42.09255**	**43.18853**	**574.6961**

Table A.44 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 2 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.6319	38.7852	39.6762	273.6237
1	34.8147	39.3152	40.0834	305.5156
2	35.3821	39.6931	40.3566	254.3378
3	34.8485	39.4394	40.6744	266.4919
4	35.8455	40.017	40.9257	261.9541
5	34.9249	39.8026	40.2622	281.8296
6	35.2495	39.3605	40.8621	270.6726
7	35.3991	39.3062	40.8056	262.9407
Average	**35.13703**	**39.4649**	**40.45578**	**272.1708**

Table A.45 Results For Breakdance Using VPBFMEA Version 1 With Refinement SW 2 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2771	40.2064	43.4063	11569.57
1	40.1989	40.7154	42.6482	12426.6
2	40.6454	40.9372	43.6635	9804.528
3	39.9658	41.2191	43.3165	11645.31
4	41.1756	41.7294	44.3818	7576.178
5	41.157	42.1592	44.2639	6871.331
6	41.0399	41.8216	44.9404	6988.037
7	40.7567	41.5969	43.1481	9039.983
Average	**40.65205**	**41.29815**	**43.72109**	**9490.192**

Table A.46 Results For Uli Using VPBFMEA Version 1 With Refinement SW 2 And QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.923	35.3878	39.0615	3108.509
1	34.5888	36.1969	37.6805	3253.612
2	35.6168	37.045	39.1369	2533.899
3	35.1934	37.5875	38.5985	2624.017
4	36.5828	37.8926	39.9704	1965.403
5	36.8233	38.8951	39.4964	1745.296
6	36.7105	38.0467	40.5476	1763.973
7	35.6958	37.432	38.0993	2322.289
Average	**35.7668**	**37.31045**	**39.07389**	**2414.625**

Table A.47 Results For Uli Using VPBFMEA Version 1 With Refinement SW 2 And QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.197	32.5326	36.517	893.7802
1	28.6584	33.6352	35.0268	907.3309
2	30.0184	34.8079	36.5952	765.042
3	29.7995	35.2938	35.9669	716.6099
4	31.2921	35.3589	37.4352	632.3901
5	31.6105	36.8428	36.7577	585.8148
6	31.4608	35.56	37.9898	600.2173
7	30.0828	34.8472	35.3651	690.6272
Average	**30.26494**	**34.8598**	**36.45671**	**723.9766**

Table A.48 Results For Uli Using VPBFMEA Version 1 With Refinement SW 2 And QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.5981	43.08	43.1443	4277.452
1	40.2754	42.8513	42.8763	4283.279
2	40.4037	43.194	43.2224	3866.477
3	40.2987	43.0119	42.9949	3927.521
4	40.2512	42.9351	42.8291	4103.519
5	40.5582	43.4204	43.3342	3667.632
6	40.0369	42.6769	42.7864	4652.679
7	40.1766	42.7772	42.6808	4262.98
Average	**40.32485**	**42.99335**	**42.98355**	**4130.192**

Table A.49 Results For Ballroom Using VPBFMEA Version 2 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9115	39.0112	38.9561	1120.699
1	34.8699	39.2165	38.9551	901.1481
2	35.0209	39.5754	39.4494	821.7185
3	34.6186	39.0777	39.0012	860.5852
4	34.6001	39.0367	38.7484	894.158
5	35.0202	39.3887	39.2932	861.2198
6	34.5863	39.2007	39.0383	862.9704
7	34.3452	38.7205	38.3709	927.4938
Average	**34.74659**	**39.15343**	**38.97658**	**906.2491**

Table A.50 Results For Ballroom Using VPBFMEA Version 2 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5599	36.3926	36.3471	354.8148
1	29.5505	36.6966	36.4062	311.2765
2	29.9253	37.1371	36.9668	294.7012
3	29.3452	36.6092	36.5888	300.0444
4	29.2937	36.6828	36.3689	305.079
5	29.7498	36.5895	36.6355	307.5827
6	29.6787	36.4942	36.5304	306.9432
7	28.8504	36.157	36.0213	317.4222
Average	**29.49419**	**36.59488**	**36.48313**	**312.233**

Table A.51 Results For Ballroom Using VPBFMEA Version 2 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0934	42.8809	42.5769	3663.968
1	40.0379	42.8646	42.4283	3856.788
2	40.2632	43.2902	42.8034	3406.995
3	40.1244	43.1481	42.9489	3374.341
4	40.0594	42.9855	42.7278	3360.341
5	40.6044	43.9913	43.524	2613.827
6	39.9814	42.6929	42.2229	4480.568
7	40.1366	42.905	42.5691	3449.674
Average	**40.16259**	**43.09481**	**42.72516**	**3525.813**

Table A.52 Results For Vassar Using VPBFMEA Version 2 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9222	40.1843	39.4598	419.916
1	34.8523	40.3686	39.3345	357.1654
2	35.1521	40.9827	39.8171	331.3037
3	34.9234	40.6627	40.2418	343.0914
4	34.7406	40.3309	39.6446	336.8
5	35.484	41.7011	40.8262	312.9136
6	34.5966	40.4022	39.1956	412.4741
7	34.6943	40.2816	39.6358	395.4123
Average	**34.92069**	**40.61426**	**39.76943**	**363.6346**

Table A.53 Results For Vassar Using VPBFMEA Version 2 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7995	38.4162	37.5277	129.116
1	30.7614	38.874	37.5446	139.0444
2	31.1127	39.4361	38.0624	127.6667
3	30.7642	39.2536	38.7253	125.4247
4	30.6642	39.0198	37.9087	131.6914
5	31.1633	40.0777	39.2859	134.2247
6	30.4069	39.0618	37.7204	134.6395
7	30.1779	38.8321	38.2569	135.8296
Average	**30.73126**	**39.12141**	**38.12899**	**132.2046**

Table A.54 Results For Vassar Using VPBFMEA Version 2 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9203	44.1888	45.3058	4216.93
1	41.2402	44.7876	45.6451	3266.239
2	41.0913	44.6013	45.6709	3217.741
3	41.2518	44.5748	46.4875	3074.11
4	41.241	44.4969	46.3786	3155.625
5	41.1747	44.6233	45.8455	3294.559
6	41.0591	44.464	45.9789	3183.397
7	41.1633	44.385	45.8433	3411.123
Average	**41.14271**	**44.51521**	**45.89445**	**3352.465**

Table A.55 Results For Breakdance Using VPBFMEA Version 2 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8827	41.5855	42.3408	715.0726
1	38.1763	42.2435	42.8944	540.3778
2	38.2848	42.3199	42.963	475.1022
3	38.1917	42.1127	43.7269	524.4104
4	38.5226	42.4244	43.905	486.203
5	38.0834	42.2334	43.0189	533.8504
6	38.2537	42.0355	43.4852	499.9393
7	38.2776	42.0404	43.2374	511.3422
Average	**38.2091**	**42.12441**	**43.19645**	**535.7872**

Table A.56 Results For Breakdance Using VPBFMEA Version 2 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.6319	38.7852	39.6762	273.6237
1	34.7709	39.3401	40.0873	272.6919
2	35.3588	39.6399	40.3171	254.12
3	34.837	39.4426	40.6589	253.837
4	35.8992	40.0484	40.9391	252.3852
5	34.9314	39.7966	40.2567	267.9467
6	35.2268	39.3479	40.8377	259.0356
7	35.4641	39.3194	40.8057	252.4193
Average	**35.14001**	**39.46501**	**40.44734**	**260.7574**

Table A.57 Results For Breakdance Using VPBFMEA Version 2 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2771	40.2064	43.4063	11569.57
1	40.2005	40.7209	42.6515	12446.1
2	40.6436	40.9402	43.6585	9806.304
3	39.9661	41.217	43.3138	11666.69
4	41.1747	41.7283	44.39	7576.128
5	41.1497	42.1548	44.2689	6865.032
6	41.0413	41.8218	44.9363	7000.286
7	40.7495	41.6004	43.1459	9032.18
Average	**40.65031**	**41.29873**	**43.7214**	**9495.286**

Table A.58 Results For Uli Using VPBFMEA Version 2 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.923	35.3878	39.0615	3108.509
1	34.5964	36.2002	37.6772	3275.099
2	35.6373	37.0597	39.1378	2537.136
3	35.205	37.5805	38.6094	2644.652
4	36.5947	37.8946	39.99	1965.78
5	36.8157	38.866	39.5086	1745.603
6	36.7209	38.0604	40.5245	1774.738
7	35.7048	37.422	38.0999	2329.02
Average	**35.77473**	**37.3089**	**39.07611**	**2422.567**

Table A.59 Results For Uli Using VPBFMEA Version 2 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.197	32.5326	36.517	893.7802
1	28.6753	33.607	35.0547	912.3037
2	30.0742	34.8114	36.5803	767.6173
3	29.8322	35.2524	35.9886	724.5185
4	31.3388	35.3502	37.4294	630.6617
5	31.6122	36.79	36.7322	586.2099
6	31.4716	35.5671	37.9459	602.8049
7	30.1057	34.8334	35.3378	699.3728
Average	**30.28838**	**34.84301**	**36.44824**	**727.1586**

Table A.60 Results For Uli Using VPBFMEA Version 2 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.5981	43.08	43.1443	4277.452
1	40.2743	42.8511	42.8776	4269.368
2	40.4029	43.1944	43.2229	3864.995
3	40.2983	43.0115	42.9949	3927.41
4	40.251	42.9352	42.8291	4103.82
5	40.5583	43.4204	43.3345	3668.321
6	40.0366	42.677	42.7865	4652.407
7	40.1762	42.7776	42.6801	4262.124
Average	**40.32446**	**42.9934**	**42.98374**	**4128.237**

Table A.61 Results For Ballroom Using VPBFMEA Version 3 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9115	39.0112	38.9561	1120.699
1	34.8697	39.2173	38.9547	896.0617
2	35.0216	39.5767	39.4495	820.5481
3	34.6191	39.0786	39.0027	860.3383
4	34.5999	39.0375	38.7499	894.363
5	35.0192	39.3886	39.2908	860.9926
6	34.5857	39.1987	39.0359	863.084
7	34.3445	38.7207	38.3712	927.4864
Average	**34.7464**	**39.15366**	**38.97635**	**905.4466**

Table A.62 Results For Ballroom Using VPBFMEA Version 3 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5599	36.3926	36.3471	354.8148
1	29.5481	36.6987	36.4106	305.9877
2	29.9248	37.1388	36.9635	294.5605
3	29.3471	36.6122	36.5895	300.6272
4	29.2926	36.6791	36.3688	305.3062
5	29.7488	36.5848	36.6379	307.8247
6	29.6761	36.4968	36.5302	306.884
7	28.8496	36.1577	36.0217	317.5062
Average	**29.49338**	**36.59509**	**36.48366**	**311.6889**

Table A.63 Results For Ballroom Using VPBFMEA Version 3 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0934	42.8809	42.5769	3663.968
1	40.0378	42.8645	42.4284	3855.884
2	40.2633	43.2903	42.8034	3407.022
3	40.1244	43.1482	42.9488	3374.257
4	40.0594	42.9854	42.728	3360.321
5	40.6044	43.9912	43.524	2613.807
6	39.9814	42.6929	42.223	4480.607
7	40.1366	42.905	42.569	3449.694
Average	**40.16259**	**43.0948**	**42.72519**	**3525.695**

Table A.64 Results For Vassar Using VPBFMEA Version 3 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9222	40.1843	39.4598	419.916
1	34.8495	40.3661	39.3333	347.9975
2	35.1519	40.9824	39.8168	331.084
3	34.9234	40.6629	40.242	343.2198
4	34.7406	40.331	39.6445	336.7556
5	35.4841	41.7012	40.8261	312.9679
6	34.5966	40.4023	39.1955	412.4395
7	34.6943	40.2817	39.6358	395.442
Average	**34.92033**	**40.61399**	**39.76923**	**362.4778**

Table A.65 Results For Vassar Using VPBFMEA Version 3 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7995	38.4162	37.5277	129.116
1	30.7556	38.8736	37.5498	132.7481
2	31.1116	39.4329	38.0604	127.4914
3	30.764	39.2508	38.7259	125.6099
4	30.664	39.0186	37.9073	131.6593
5	31.1636	40.0774	39.2838	134.2815
6	30.4071	39.0622	37.7207	134.4691
7	30.1778	38.8321	38.2576	135.763
Average	**30.7304**	**39.12048**	**38.12915**	**131.3923**

Table A.66 Results For Vassar Using VPBFMEA Version 3 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.9203	44.1888	45.3058	4216.93
1	41.2402	44.7854	45.6397	3281.907
2	41.0917	44.6027	45.6685	3218.813
3	41.252	44.5749	46.4866	3075.769
4	41.2408	44.496	46.3775	3155.059
5	41.1737	44.6218	45.8442	3292.686
6	41.0589	44.4639	45.9777	3182.938
7	41.1631	44.3852	45.8418	3410.48
Average	**41.14259**	**44.51484**	**45.89273**	**3354.323**

Table A.67 Results For Breakdance Using VPBFMEA Version 3 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8827	41.5855	42.3408	715.0726
1	38.1655	42.2267	42.8815	544.1333
2	38.2865	42.3144	42.9565	476.117
3	38.1901	42.1094	43.7257	524.3867
4	38.5247	42.4256	43.9099	485.8681
5	38.0843	42.2322	43.0213	532.9926
6	38.2546	42.0369	43.4872	500.4193
7	38.2796	42.0393	43.2352	511.2519
Average	**38.2085**	**42.12125**	**43.19476**	**536.2802**

Table A.68 Results For Breakdance Using VPBFMEA Version 3 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.6319	38.7852	39.6762	273.6237
1	34.714	39.3103	40.0729	269.2904
2	35.34	39.6268	40.3081	254.7526
3	34.8308	39.4407	40.6576	254.3304
4	35.897	40.0481	40.9458	253.1585
5	34.9315	39.7919	40.2609	267.9126
6	35.2298	39.3438	40.8346	259.5541
7	35.467	39.3216	40.81	252.5556
Average	**35.13025**	**39.45855**	**40.44576**	**260.6472**

Table A.69 Results For Breakdance Using VPBFMEA Version 3 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2771	40.2064	43.4063	11569.57
1	40.2005	40.7211	42.6518	12444.75
2	40.6436	40.9402	43.6586	9806.274
3	39.9661	41.217	43.3138	11666.75
4	41.1747	41.7283	44.39	7576.124
5	41.1497	42.1548	44.2689	6865.03
6	41.0413	41.8218	44.9363	7000.286
7	40.7495	41.6004	43.1459	9032.18
Average	**40.65031**	**41.29875**	**43.72145**	**9495.12**

Table A.70 Results For Uli Using VPBFMEA Version 3 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.923	35.3878	39.0615	3108.509
1	34.5967	36.1999	37.677	3273.42
2	35.6373	37.0599	39.1376	2536.911
3	35.205	37.5809	38.6096	2644.625
4	36.5947	37.8946	39.99	1965.785
5	36.8157	38.866	39.5087	1745.585
6	36.7209	38.0604	40.5246	1774.731
7	35.7048	37.4219	38.0999	2329.049
Average	**35.77476**	**37.30893**	**39.07611**	**2422.327**

Table A.71 Results For Uli Using VPBFMEA Version 3 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.197	32.5326	36.517	893.7802
1	28.6729	33.6054	35.0566	906.121
2	30.0743	34.8109	36.5803	767.6568
3	29.8323	35.2522	35.9887	724.4519
4	31.3391	35.35	37.4296	630.837
5	31.6122	36.7901	36.7322	586.2222
6	31.4716	35.5672	37.9459	602.8198
7	30.1057	34.8335	35.3378	699.3951
Average	**30.28814**	**34.84274**	**36.44851**	**726.4105**

Table A.72 Results For Uli Using VPBFMEA Version 3 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.6009	43.0781	43.1436	4288.363
1	40.2927	42.8495	42.8763	4372.943
2	40.424	43.1856	43.2163	3943.23
3	40.3205	43.0139	42.9832	4020.812
4	40.2753	42.9334	42.8207	4215.077
5	40.585	43.406	43.3299	3762.18
6	40.0588	42.6632	42.7865	4750.916
7	40.204	42.7748	42.6731	4388.842
Average	**40.34515**	**42.98806**	**42.9787**	**4217.795**

Table A.73 Results For Ballroom Using VPBFMEA Version 4 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9144	38.993	38.9472	1130.21
1	34.881	39.1666	38.9254	959.6963
2	35.0377	39.5127	39.4088	873.7012
3	34.6265	39.0346	38.9499	918.4074
4	34.6183	39.0027	38.7202	957.363
5	35.0432	39.3471	39.2384	930.1506
6	34.6167	39.1532	39.0081	929.5259
7	34.3705	38.6827	38.3289	1009.099
Average	**34.76354**	**39.11158**	**38.94086**	**963.5191**

Table A.74 Results For Ballroom Using VPBFMEA Version 4 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.5454	36.3658	36.3229	357.4395
1	29.4964	36.5992	36.3239	319.5704
2	29.8806	37.0246	36.8703	310.5975
3	29.2958	36.518	36.4945	319.5235
4	29.2466	36.5686	36.2446	327.2543
5	29.7126	36.4947	36.5054	331.5111
6	29.6536	36.3707	36.3857	329.3037
7	28.8418	36.0405	35.8892	345.2988
Average	**29.4591**	**36.49776**	**36.37956**	**330.0624**

Table A.75 Results For Ballroom Using VPBFMEA Version 4 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.0934	42.8815	42.5769	3669.299
1	40.0442	42.8721	42.4245	3865.669
2	40.2676	43.291	42.8049	3411.956
3	40.1312	43.144	42.9498	3385.872
4	40.0796	42.9903	42.7354	3380.161
5	40.6167	43.9959	43.5217	2626.193
6	39.9897	42.6931	42.2274	4500.696
7	40.1472	42.9103	42.573	3475.83
Average	**40.1712**	**43.09728**	**42.7267**	**3539.459**

Table A.76 Results For Vassar Using VPBFMEA Version 4 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9224	40.1848	39.4576	423.5309
1	34.8482	40.3586	39.3221	355.0074
2	35.1441	40.9611	39.8099	332.4296
3	34.9202	40.6305	40.246	345.3753
4	34.7332	40.3119	39.6377	342.2395
5	35.4826	41.6583	40.8212	318.1802
6	34.6015	40.3747	39.1786	420.316
7	34.6983	40.2635	39.6247	407.1827
Average	**34.91881**	**40.59293**	**39.76223**	**368.0327**

Table A.77 Results For Vassar Using VPBFMEA Version 4 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	30.7917	38.4155	37.5225	130.3235
1	30.7169	38.8522	37.5331	134.9975
2	31.0548	39.429	38.0383	126.5012
3	30.6989	39.2411	38.7251	122.9309
4	30.6013	39.006	37.8886	131.6691
5	31.1046	40.0537	39.2336	133.2198
6	30.3954	39.0116	37.7099	134.1802
7	30.1242	38.8175	38.2255	135.1827
Average	**30.68598**	**39.10333**	**38.10958**	**131.1256**

Table A.78 Results For Vassar Using VPBFMEA Version 4 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.922	44.1865	45.2979	4227.402
1	41.2448	44.7787	45.622	3351.65
2	41.1194	44.5753	45.6379	3362.519
3	41.2707	44.5585	46.477	3129.858
4	41.2577	44.4826	46.367	3171.329
5	41.2035	44.6142	45.8287	3379.964
6	41.094	44.4421	45.9491	3240.876
7	41.184	44.3818	45.8201	3421.953
Average	**41.16201**	**44.50246**	**45.87496**	**3410.694**

Table A.79 Results For Breakdance Using VPBFMEA Version 4 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	37.8771	41.5655	42.3153	718.1778
1	38.1619	42.17	42.851	568.5763
2	38.2584	42.1528	42.8608	545.3674
3	38.1695	41.9819	43.6929	551.9837
4	38.5214	42.3085	43.8511	497.6104
5	38.078	42.0551	42.9828	574.5274
6	38.2592	41.9325	43.363	526.9689
7	38.2796	41.939	43.1394	523.9867
Average	**38.20064**	**42.01316**	**43.13204**	**563.3998**

Table A.80 Results For Breakdance Using VPBFMEA Version 4 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	34.593	38.7674	39.6542	271.4815
1	34.5509	39.2527	40.0383	268.8267
2	35.0848	39.3586	40.1731	269.9867
3	34.6257	39.231	40.5941	259.2933
4	35.7116	39.8531	40.8589	252.8756
5	34.7006	39.539	40.1826	273.7467
6	35.0225	39.2358	40.6642	259.6489
7	35.2843	39.2855	40.6356	253.9881
Average	**34.94668**	**39.31539**	**40.35013**	**263.7309**

Table A.81 Results For Breakdance Using VPBFMEA Version 4 With QP 42

QP 22				
View	Y	U	V	Bit Rate
0	40.2768	40.2068	43.4057	11568.96
1	40.2106	40.7244	42.6532	12456.89
2	40.6561	40.9418	43.6583	9818.622
3	39.9706	41.2225	43.3161	11677.82
4	41.1822	41.7271	44.3892	7580.099
5	41.1621	42.1629	44.2672	6875.778
6	41.0531	41.8247	44.9472	7016.012
7	40.761	41.6004	43.1443	9044.899
Average	**40.65906**	**41.30133**	**43.72265**	**9504.885**

Table A.82 Results For Uli Using VPBFMEA Version 4 With QP 22

QP 32				
View	Y	U	V	Bit Rate
0	34.9232	35.3868	39.0603	3106.921
1	34.614	36.2032	37.6744	3290.904
2	35.6612	37.0487	39.0898	2548.091
3	35.2132	37.5802	38.5968	2652.296
4	36.6262	37.8942	39.956	1973.395
5	36.8524	38.8652	39.486	1750.741
6	36.749	38.0554	40.4973	1791.052
7	35.726	37.4142	38.074	2341.832
Average	**35.79565**	**37.30599**	**39.05433**	**2431.904**

Table A.83 Results For Uli Using VPBFMEA Version 4 With QP 32

QP 42				
View	Y	U	V	Bit Rate
0	29.1958	32.529	36.5128	891.3259
1	28.7194	33.5822	35.0338	903.1407
2	30.1304	34.7456	36.51	763.9802
3	29.8466	35.229	35.9474	721.9407
4	31.3978	35.3168	37.3721	630.4099
5	31.6501	36.769	36.7078	579.7778
6	31.5142	35.5149	37.8548	602.3506
7	30.13	34.8037	35.2707	696.4938
Average	**30.32304**	**34.81128**	**36.40118**	**723.6775**

Table A.84 Results For Uli Using VPBFMEA Version 4 With QP 42