Analysis of Lossy Video Compression Technique

Mahesh Kamat[1], Prof. Roopa Kulkarni[2] and Dr. Prashant Patavardhan[3]

[1] PG Student, Department of Electronics & Communication Engineering, KLS Gogte Institute of Technology Belagavi, Karnataka, India Email:maheshkamat369@gmail.com
[2] Research Center, Department of Electrical & Electronics Engineering, KLS Gogte Institute of Technology Belagavi, Karnataka, India Email:roopa.patavardhan@gmail.com
[3] Research Center, Department of Electrical & Electronics Engineering, KLS Gogte Institute of Technology Belagavi, Karnataka, India Email: pppatavardhan@git.edu

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Abstract - ***Video compression techniques, there has been vast research over the years on design of codecs for the digital videos. This paper gives the study of various parameters (parameters like block size, motion estimation scheme, slow medium and fast motion videos, high and medium compressed videos and with or without scaling of DCT coefficients) of video processing. After these study, best parameters that can be used for an efficient codec is described.***

Key Words: *Motion Estimation, Digital Video Coding, DCT, CR, PSNR, etc...*

1. INTRODUCTION

With the advancement in multimedia communication technology, it is advent that use of images for communication is better than text, similarly it is seen that use of video communication is better than images. In today's world the use of multimedia gadgets like cell phones, laptops, camera etc. is enormous. This leads to study of multimedia communication which includes the basic understanding of video and its processing techniques. Video is a set of images (frames) running continuously that creates an illusion of pictures in a motion.

Over the past decades, the video compression has been playing a vital role in data transmission and storage as it is the main focus in several applications such as multimedia communications, videophones, remote monitoring, videoconference and many. It has become very important and interesting area of research. The innovations of new technologies lead a path of new communication system that involved video information. Because of the enormous high quality information to be stored in memory and transmitted, so there is a need for video compression.

There are two ways in which data compression can be achieved. Firstly reversible or lossless compression in which the original video can be completely retraced from compressed form without any loss of visual content. It is most of the times limited to compression ratios of less than or equal to 4:1 ratio. Secondly there is irreversible or lossy compression technique. By lossy technique there can be higher compression ratios achieved than lossless compression, but it may introduce degradation or error into the video so that the original visual information cannot be perfectly regenerated. The performance of any encoder is determined by the bit rate it achieves, which presents the compression ratio and the degradation or distortion between originals and decoded frames introduced by the encoder. Luckily, most frames has some redundancy which can sometime be discarded when the frame is transmitted or stored in memory and replaced when it is retraced and this can be exploited in order to get reduced the amount of visual data necessary for their representation. The human eye is insensitive to a wide variety of visual information. That is frames can be changed in several ways and cannot be detected by human eyes.

2. RELATED WORK

In this section, a review of different motion estimation method, transformation schemes and performance parameter is given so that an efficient codec is designed.

2.1 Motion Estimation:

K. R. Namuduri and Aiyuan Ji [1] presented a paper entitled "Computation and Performance Trade-offs in Motion Estimation Algorithms" which gave the knowledge of understanding the various trade-offs like processing speed, power consumption and video quality here the authors has studies these trade-offs for three search algorithms: NTSS (New Three Step Search), FSS (Four Step Search) and DS (Diamond search). The authors concluded that DS is the closest approximation to the ES (Exhaustive Search) with better trade-offs when compared with other algorithms.

Aroh Barjatya [2] presented a paper entitled "Block Matching Algorithms for Motion Estimation" this gave the study of motion estimation algorithms used for video compression, a comparison of 7 different types of block matching techniques is extensively studied, starting from the basic approach of block matching that is the ES to the latest approach that is ARPS (Adaptive Rood Pattern Search). The author concludes that the ARPS is the best Block Matching technique which can be used for the video compression since it requires less time and is a complex technique.

Jian-Liang Lin, Yi-Wen Chen, Yu-Wen Huang, and Shaw-Min Lei [3] presented a paper entitled "Motion Vector Coding in the HEVC Standard" which provided the overview of the motion vector coding techniques in High Efficient Video Coding. The proposed algorithm was such that it included an algorithm like priority based derivation for temporal motion block, priority based derivation for spatial motion block and surrounding based motion block. Finally the authors conclude that after combining the effects of these three algorithms together will give on an average 3% bit rate saving which was big deal for video coding so this was adapted in HEVC standard.

Shaifali Madan Arora and Navin Rajpal [4] presented a paper entitled "Comparative Analysis of Motion Estimation Algorithms on Slow, Medium and Fast Video Sequences" which gave the comparison and analysis of the various motion estimation algorithms for these three types of video sequence. The motion estimations techniques considered in this paper are ES, TSS (Three Step Search), NTSS, DS and ARPS. The performance of these algorithms is evaluated based on PSNR, time required to determine the motion vector and number of computations performed. Finally the authors concludes after a greater study of algorithms that in terms of PSNR, DS gives better results for slow motion video sequence, similarly for medium motion video sequence NTSS gives better results whereas for fast motion video sequence TSS is well suited. But when compared to ARPS algorithm it overcomes performance of all the video sequence and gives best results for the three category slow, medium and fast sequences. But there is one significant loss of PSNR is noticed in fast motion video sequence for fixed block size techniques when compared with slow and medium motion video sequences. So there is a need to develop a better codec such that it performs well even for the fast motion video sequence.

2.2 Transform scheme:

Zixiang Xiong, Kannan Ramchandran, Michael T. Orchard, and Ya-Qin Zhang [5] presented a paper entitled "A Comparative Study of DCT and Wavelet Based Image Coding" which undertakes the study of performance difference between DCT and DWT for image and video coding. The authors conclude after studying the results they were getting that DWT out performs DCT by the order of 1 dB in PSNR for still images, whereas for video coding there is not much advantage of DWT. Any video codec system can be evaluated based on its overall system address that is quantization, entropy coding and complex interplay among elements of the coding system. These three play an important role than rather only optimizing the transform technique.

Shizhong Liu [6] presented a paper entitled "Local Bandwidth Constrained Fast Inverse Motion Compensation for DCT-Domain Video Transcoding" which showed the popularity of video coding based on DCT for H.26x and MPEG. Since the standards were different for each format a video transcoder was used to convert video from one format into another as per the channel bandwidth and video composition. The author says that DCT based transcoding in more efficient than spatial based transcoding. However data is well organized in block by block so that inverse motion compensation becomes a bottle neck for DCT. This paper presents fast inverse motion compensation technique for DCT working on local bandwidth. The proposed algorithms shows 25% to 55% improvement without and visual degradation as compared with Chang's algorithm, this proposed algorithm can also be implemented on the existing fast motion algorithms for improved computations. A look up table based model was developed for statistically distributed DCT coefficients. By using this method there is furthermore 31% to 48% improvement in computations whereas the memory required for look up table is 800 kB which is considerable for implementation. Another important feature of this look up table is that it can be used for multiple DCT based video processing which are running on same PC or video server.

Bing Zeng and Jingjing Fu [7] presented a paper entitled "Directional Discrete Cosine Transform – A New Framework for Image Coding" which shows the new method for working with DCT nearly all previous algorithms used 2-D DCT for a square block shape. This algorithm proposed works on 1-D DCT separately one for horizontal and other for vertical direction. In this paper the first frame may choose the direction to follow other than vertical and horizontal, the coefficients produced by the first transform step are aligned so that it is well suited for the second transform. After computations is done the resulting block when compared with regular DCT, the Directional DCT proposed in this paper provides better performance than the normal DCT for the blocks containing directional edges. By choosing best case for directional DCT it can be shown that performance of rate-distortion coding can be improved. Finally the author concludes giving the theoretical reasons for the coding gain achieved from this proposed algorithm for directional DCT.

Xin Zhao, Li Zhang, Siwei Ma, and Wen Gao [8] presented a paper entitled "Video Coding with Rate-Distortion Optimized Transform" which started on the bases that block based DCT was universally approved and adapted in several video coding techniques since it has a capacity to achieve better performance and complexity. As DCT has approximated theoretically for the first order Markov conditions over Karhunen-Loeve transform for optimal results. Due to the non-stationary nature of any video sequence the transform basis functions cannot handle it efficiently. In this paper for greater improvement in block based transforms the new design of rate distortion optimized transform is presented for both inter and intra based frame coding. The main criteria on which rate distortion optimum transform differs with discrete cosine transform is that for the proposed system uses transform basis function for the candidate block obtained by off-line training. With all of these techniques the encoding is capable of achieving optimal set of transform basis functions for the rate distortion performance so that there is greater energy compaction in transform domain. To obtain optimal results two-step iteration technique is used for transform basis functions each iteration refines the training sequence in order to conserve the energy into the transform domain. The author has also provided optimum group of candidates for transform basis function with detailed description of implementing it practically on the software VCEG. Finally the authors conclude that there is some significant improvements in the coding performance in inter and intra frame coding as compared with DCT used for H.264/AVC.

2.3 Performance parameter:

Q. Huynh-Thu and M. Ghanbari [9] presented a paper entitled “Scope of Validity of PSNR in Image/Video Quality Assessment” which validates the exactness of the performance parameter for variation of codecs and video sequence and having the same codec and video sequence, and authors has written based on the exhaustive experimental data that the PSNR is the scope of application for video quality assessment. It is also shown that as long as that PSNR is a valid measure until the video sequence or the codec type is changed, However if there is a change in any of the video content or video codec type then there is a large correlation noticed between subjective quality and PSNR which is drastically reduced. Finally the authors conclude saying that PSNR cannot be used as a reliable method for assessing the video quality from different video contents.

3. METHODOLOGY

Designing of an efficient codec for video processing is essential Fig- 1 gives the generic block diagram for video compression.

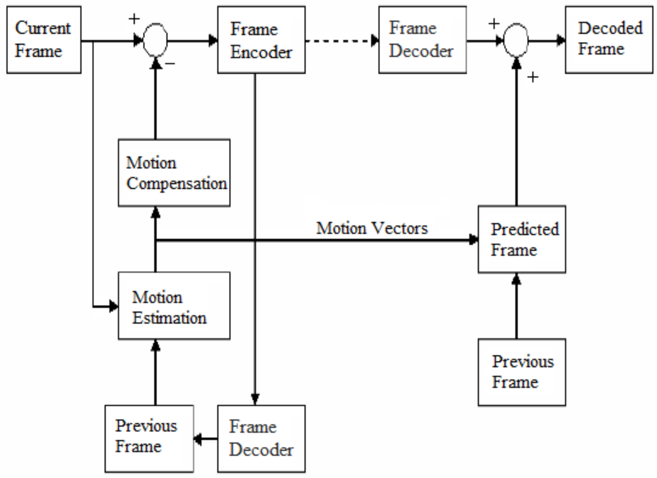

Fig -1: Block Diagram for H.26x/MPEG video compression.

3.1 Motion Estimation (ME):

Firstly the current frame is divided into non overlapping blocks of the block size, then for each block the best match is found in the next frame. This means that motion estimation involves finding the block in the current frame present in the next frame into the confined search window. As in the literature survey the various techniques for motion estimation is studies. For each video sequence, these three motion estimation technique is used Exhaustive Search, Diamond Search and Adaptive Rood Pattern Search. After having used these three techniques finally there will be comparison of these techniques from the results obtained.

3.2 Motion Compensation:

After getting the motion vectors for the current frame, the motion compensation block uses these motion vectors and the current frame to find the estimated next frame, the job of the motion compensation is to consider the current frame and as per the motion vectors and create the predicted next frame. Now there are two next frames one is actual next frame and other is predicted next frame, so the subtraction of these two frames will give us the residual frame which is further sent for encoding. As defined in equation (1)

$$D(t) = \Psi(t) - \Psi'(t) \qquad (1)$$

Where $\Psi(t)$ is the current frame, $\Psi'(t)$ is the predicted version of the current frame and $D(t)$ is the residual frame that is sent further for encoding.

3.3 Frame Encoder:

The frame encoder has many functions to perform these functions are explained in depth in this section. As the result of subtraction the residual frame will have almost zeros values at every pixels and some part of the frames also may have other values which is unexpected error due to motion estimation, for having good video quality this residual error should be encoded so that finally at the decoder this error can be negated. The steps involved in encoding are transforming, zigzag scanning, run length coding and finally converting into code-words, each of these are explained below:

3.3.1 Transformation

There are various transformation techniques like Discrete Cosine Transform, Discrete Sine Transform, Discrete Fourier Transform, Wavelet Transform and many more. Here in this codec only DCT is used. The transformation such as DCT is used to change the pixel values in the residual frames into frequency domain coefficients. These coefficients have many properties one of them is energy compaction this property tell us that entire strength of the residual frame $D(t)$ is compacted in some of the important coefficients. Only these coefficients are selected and the remaining coefficients are ignored, this selection of the coefficients is based on the order of the scanning which will be explained later. The 2-D DCT used here can be defined as follows in equation (2),

$$F(u,v) = \frac{2}{N} C(u) C(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right] \quad (2)$$

For u = 0… N-1 and v = 0… N-1

where N= block size and $C(k) = \begin{cases} \frac{1}{\sqrt{2}} & for\ k = 0 \\ 1 & otherwise \end{cases}$

3.3.2 Scanning

There are various ways of scanning DCT coefficients alternate scan, zigzag scan and many more, here in this thesis Zigzag scan is implemented. Figure 2 shows the scanning order of Zigzag scan for block size = 8. This shows how the AC and DC coefficients are scanned after DCT. For better understanding let us consider an example of AC and DC coefficients for a block size = 4, which is as shown in the Figure 3. The output of Zigzag scan will have all the AC and DC coefficients of DCT transform rearranged and made ready for run-length encoding.

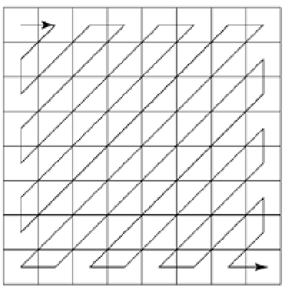

Fig – 2: After DCT, Zigzag scan order

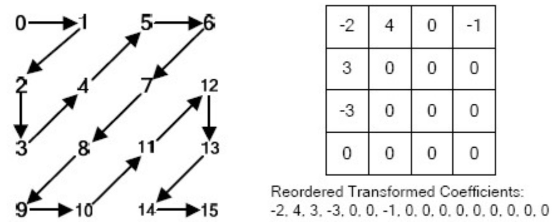

Fig- 3: Example of Zigzag Scanning and its output for block size = 4.

3.3.3 Run Length Coding

Run-Length coding is a type of coding such that the values given to it will be seen to it that how many times it is being repeated. This process of run-length coding is applied to the output of zigzag scan. As in the output of the previous example the run length encoding is calculated until EOB (End Of Bit) is achieved or maximum number of mask coefficients are acquired as defined by the user during initialization here 9.375% and 50% of coefficients are masked in order to produce high compressed and medium compressed video sequence respectively. Below is the output of run length coding defined in the example for zigzag scan for block size = 4.

[(value1, run1) (value2, run2) …] = [values . . .]

[(-2, 1) (4, 1) (3, 1) (-3, 1) (0, 2) (-1, 1) (EOB)] = [-2 4 3 -3 0 0 -1 0 0 0 0 0 0 0 0 0]

3.3.4 Code-words

After run-length coding the output of it should be assigned with code-words, this can be achieved by various techniques like Huffman coding and many more but here in this thesis since the MATLAB stores the numbers in the format of double or integer type depending on the variable data type so the conversion of these variables into string that all the variables are converted into having ASCII values, this process of conversion is overhead and time consuming in MATLAB since each value of the variable is to be converted one by one into string. In this process the serialization of all the frames and block data is done. This output is stored in a file and this is the compressed version of the video sequence.

This same process is done in reverse order to get back the decoded video sequence.

4. RESULTS AND DISCUSSION

For each and every case possible, the values of compression ratio (CR) along with time required for Motion Estimation are as tabulated in the following tables given below. In every table the compression ratio is calculated as per the equation (3), where the compressed file size is the result of the implementation and original size is as calculated below. Since CIF video sequence is used height and width will be 288 and 352 respectively and the video sequence is in YUV (4:2:0) format.

$$Original\ file\ size = \left[(352 * 288) + 2 * \left(\frac{352}{2} * \frac{288}{2}\right)\right] * 30\ Frames = 4.35\ Mb$$

$$CR = \frac{Original\ file\ size}{Compressed\ file\ size} \quad (3)$$

The ratio of the maximum power of the signal to the actual power of the signal is known as PSNR (Peak Signal to Noise Ratio). PSNR is normally expressed in dB. PSNR is most of the times used in the quality evaluation of the lossy compressed images or videos. But one thing that has to be kept into the mind that PSNR can be used for quality measurement on images or videos which work on the same codecs and the same video contents else it is invalid or PSNR shows error values. The PSNR is defined as in the equation (4)

$$PSNR = 10 \cdot log_{10} \frac{(2^b - 1)^2}{MSE} \quad (4)$$

where b is Pixel depth and MES (Mean Squared Error) which are defined below.

Pixel Depth (b) can be defined as the number of bits used per pixels to represent any video or images. Generally this value is 8 bits but sometimes higher end high definition digital video process has 11 bits per pixel.

Mean Squared Error is defined as the mean of the square of the error difference between the actual video frames and the decoded video frames. This can be represented as in equation (5)

$$MSE = \frac{1}{M\,x\,N} \sum_M \sum_N (f(m,n) - f'(m,n))^2 \quad (5)$$

where M and N are width and height of the video sequence and f and f' is sequence of video frames before and after video compression respectively.

Tables 1, 2 and 3 gives the tabulation of the results obtained for Akiyo, BBB and Bus sequence respectively, each table gives the results for motion estimation techniques ES (Exhaustive Search), DS (Diamond Search) and ARPS (Adaptive Rood Pattern Search), these ME techniques are again iterated based on block sizes 8, 16, 32 each of which with high and medium compression, for these combinations average ME time is noted and the compression ratio is tabulated.

Table -1: Results for the Implemented Codec for Akiyo Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.4948	9.20
		Medium	2.4879	2.63
	16	High	4.111	9.96
		Medium	4.188	2.55
	32	High	9.2198	9.87
		Medium	8.8683	2.41
DS	8	High	1.1345	9.33
		Medium	1.1268	2.65
	16	High	0.3668	10.05
		Medium	0.3458	2.55
	32	High	0.174	9.87
		Medium	0.1657	2.41
ARPS	8	High	0.8073	9.49
		Medium	0.7482	2.65
	16	High	0.241	10.03
		Medium	0.2294	2.55
	32	High	0.0903	9.87
		Medium	0.0856	2.41

Table -2: Results for the Implemented Codec for BBB Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.3942	7.01
		Medium	2.3855	2.01
	16	High	4.1329	7.96
		Medium	4.1935	2.01
	32	High	9.274	7.52
		Medium	9.2899	1.87
DS	8	High	1.1189	7.05
		Medium	1.1125	2.00
	16	High	0.4348	7.94
		Medium	0.4241	2.01
	32	High	0.2029	7.52
		Medium	0.191	1.88
ARPS	8	High	0.8398	7.13
		Medium	0.7937	2.00
	16	High	0.2852	7.94
		Medium	0.2914	2.01
	32	High	0.1248	7.52
		Medium	0.1195	1.88

Table -3: Results for the Implemented Codec for Bus Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.7751	4.02
		Medium	2.6766	0.94
	16	High	4.4094	4.77
		Medium	4.4476	1.07
	32	High	9.1917	4.64
		Medium	9.4456	1.02
DS	8	High	1.4795	3.99
		Medium	1.5924	0.93
	16	High	0.6115	4.43
		Medium	0.5885	0.98

	32	High	0.2739	4.48
		Medium	0.2679	0.97
ARPS	8	High	1.1759	4.02
		Medium	1.1736	0.93
	16	High	0.3689	4.64
		Medium	0.3573	1.03
	32	High	0.1583	4.54
		Medium	0.1458	1

After comparing the results in some implementations of the video sequence bus, due to the high motion the compression ratio becomes less than one, to overcome this there is further need of some more compression this can be achieved by scaling the DCT coefficients. The results for all the same three videos are again tabulated with scaling in the upcoming tables.

Tables 4, 5 and 6 gives the tabulation of the results obtained for Akiyo, BBB and Bus sequence respectively with DCT coefficients scaling.

Table -4: Results for the Implemented Codec with Scaling of DCT coefficients for Akiyo Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.3359	10.58
		Medium	2.3278	3.08
	16	High	3.8869	11.66
		Medium	3.9183	3
	32	High	8.7831	11.63
		Medium	8.8822	2.82
DS	8	High	1.0377	10.75
		Medium	1.0248	3.08
	16	High	0.346	11.75
		Medium	0.3409	3
	32	High	0.1559	11.63
		Medium	0.1574	2.82
ARPS	8	High	0.7706	10.94
		Medium	0.6882	3.08
	16	High	0.2257	11.72
		Medium	0.2158	3
	32	High	0.0997	11.63
		Medium	0.0864	2.82

Table -5: Results for the Implemented Codec with Scaling of DCT coefficients for BBB Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.343	8.04
		Medium	2.3336	2.33
	16	High	3.9444	9.43
		Medium	4.2918	2.36
	32	High	8.8453	8.94
		Medium	8.8306	2.21
DS	8	High	1.1027	8.23
		Medium	1.0752	2.33
	16	High	0.4199	9.41
		Medium	0.4028	2.36
	32	High	0.1923	8.94
		Medium	0.1902	2.21
ARPS	8	High	0.8249	8.34
		Medium	0.7722	2.33
	16	High	0.2903	9.41
		Medium	0.2844	2.36
	32	High	0.1495	8.94
		Medium	0.1173	2.21

Table -6: Results for the Implemented Codec with Scaling of DCT coefficients for Bus Sequence.

ME Tech.	Block Size	Compression type	ME Time (Seconds)	CR
ES	8	High	2.3835	4.68
		Medium	2.3579	1.13
	16	High	3.9271	5.71
		Medium	3.9201	1.30
	32	High	9.0127	5.54
		Medium	9.0015	1.24
DS	8	High	1.311	4.64
		Medium	1.3236	1.12
	16	High	0.5472	5.24
		Medium	0.5292	1.18
	32	High	0.2963	5.29
		Medium	0.2718	1.17
ARPS	8	High	1.2626	4.67
		Medium	1.1922	1.12
	16	High	0.3545	5.52
		Medium	0.3518	1.25
	32	High	0.1585	5.40
		Medium	0.156	1.2

After comparing Tables 4, 5, 6 with respective Tables 1, 2, 3 it can be said that there is decrease in motion estimation time and increase in compression ratio for scaled DCT coefficients, this betterment comes at the cost of video quality degradation which can be easily seen in Akiyo and BBB sequence but this degradation is not visible in Bus sequence due to fast motion in the sequence.

Figure 4 gives the plot of medium compressed akiyo video sequence without scaling of DCT coefficients for ARPS motion estimation algorithm and block size = 16. In the Figure it can be seen that chrominance U is constant throughout the 30 frames this is because of the less motion in video sequence.

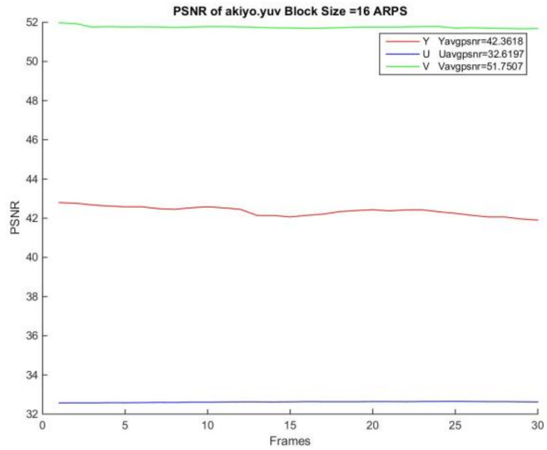

Fig -4: PSNR plot for medium compressed video without scaling.

Figure 5 gives the plot of medium compressed BBB video sequence without scaling of DCT coefficients for ARPS motion estimation algorithm and block size = 16. In the Figure it can be seen that the PSNR values for luminance and chrominance are varying, especially after frame number 15 there is sudden drop of PSNR is noticed this is due to medium motion in the video sequence.

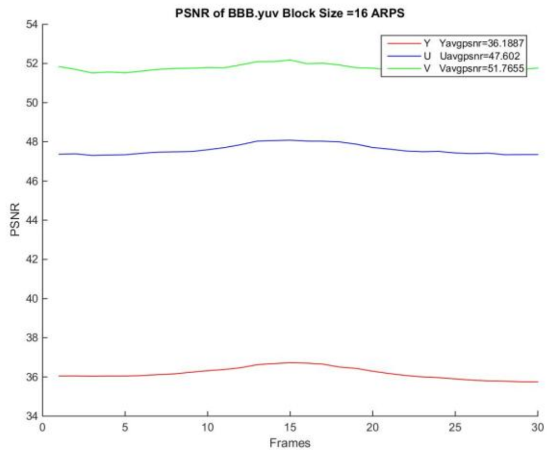

Fig -5: PSNR plot for medium compressed video without scaling.

Figure 6 gives the plot of medium compressed bus video sequence with scaling of DCT coefficients for ARPS motion estimation algorithm and block size = 16. In the Figure the drop in PSNR values for luminance and chrominance is seen because of two reasons, due to high motion in video sequence and due to scaling of DCT coefficients. But for high motion video sequence the degradation of PSNR due to scaling is not visible in video sequence.

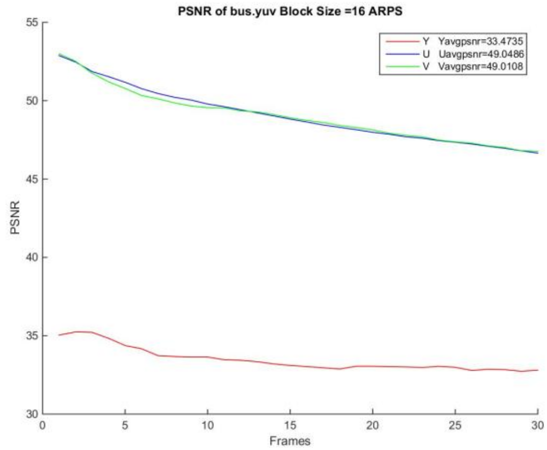

Fig -6: PSNR plot for medium compressed video with scaling.

Figure 7 gives the comparison of the video sequences considered for high and medium compressed frames with uncompressed raw frames here ARPS motion estimation technique is used and block size is 16.

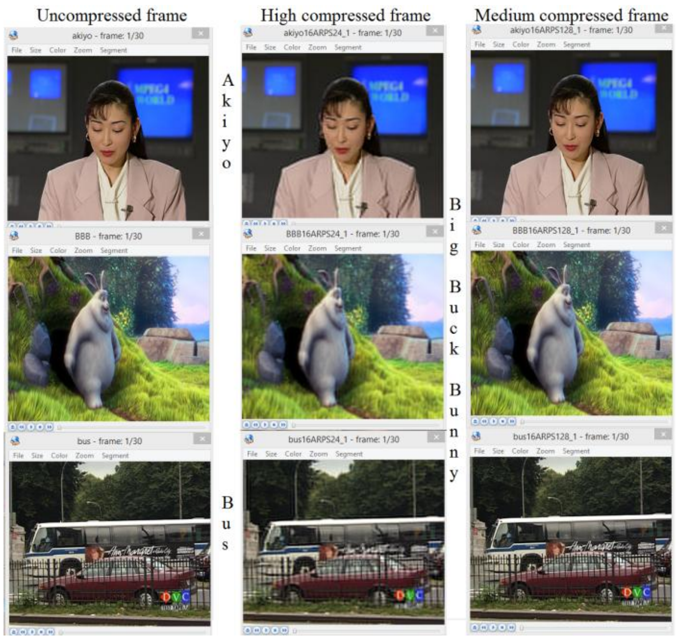

Fig -7: Comparison of the video sequence outputs (high and medium compressed video frame) with input (uncompressed video frame)

5. CONCLUSION

The analysis of the implemented codec is done on low, medium and high motion videos based on variation of motion estimation techniques, block size, compression type and scaling of DCT coefficients. After thorough analysis, the conclusion is that ARPS motion estimation techniques is well suited for all the three videos, block size 16 is considered to have better compression ratio, compression type depends on the application served if the application requires good visual quality then medium compression is selected else high compression is considered, it is advised to have scaling of DCT coefficients for video sequence with high motion.

For Akiyo video sequence ARPS motion estimation technique, block size = 16, medium compressed or 50% masking of DCT coefficient and without scaling of DCT coefficient are well suited. For BBB video sequence ARPS motion estimation technique, block size = 16, medium compressed or 50% masking of DCT coefficient and without scaling of DCT coefficient are well suited. For Bus video sequence ARPS motion estimation technique, block size = 16, medium compressed or 50% masking of DCT coefficient and with scaling of DCT coefficient are well suited.

6. FUTURE SCOPE

To overcome the degradation for the implemented codec, the N frames can be designed as I, P and B group of frames in MPEG codecs. This implementation can be worked such that coding the scaled DCT coefficients gives no degradation.

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BIOGRAPHIES

	**Mahesh Kamat** is Postgraduate student at KLS Gogate Institute of Technology, Visvesvaraya Technological University, India. His research interest includes Image processing, Video processing and Cryptography.
	**Roopa R. Kulkarni** is presently working as Assistant Professor in the Department of E & C Engg., KLS Gogte Institute of Technology, Belagavi. She is pursuing her Ph.D. in the feild of Low Power VLSI. She has 15 years of teaching experience. Her areas of interest include analog and digital VLSI, Low Power VLSI, Embedded Systems, IOT, and Cryptography to VLSI.
	**Prashant P. Patavardhan** was born on 31st May 1973. He received the B.E. degree in Electronics and Communication Engineering from the Karnataka University, Dharwad, in 1995, the M.Tech. degree in Digital Electronics and Communication Systems from Visvesvaraya Technological University, Belgaum, in 2000, and the Ph.D. degree in Faculty of Electrical and Electronics Engineering from Visvesvaraya Technological University, Belgaum, in 2011. He is currently a Professor at the Department of Electronics and Communication Engineering, KLS Gogte Institute of Technology, Belgaum, with 17 years of Teaching experience. His research interest covers Image Processing, Iris and Skin Biometrics, Pattern Recognition and Soft-Computing Techniques, with over 20 publications.