Proposed System for Digital Video Compression using MRDWT and Adaptive Road Search Pattern

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Abstract

In this paper, we present a proposed reliable system for digital video compression. In this system we solved the shift variant problem that produced because of the motion estimation and compensation associated with using discrete wavelet transform(DWT) for the spatial domain compression. In this system the digital video is entered to the two main processes, first is frame matching for motion or temporal redundancy detection, and the second is the multi resolution DWT for band and spatial domains redundancy detection, then the result of the decomposition is entered to a multi-level energy quantization before entering the entropy encoder. The proposed system was executed based on conventional video compression system and proposed video compression system. Many digital video movies with different motions (simple, complex) are used in testing the two systems, the results of compression ratio, resolution of decompressed video, and required processing time are compared. All the programs and graphics are executed using MATLAB version R2008a.

KEYWORDS: Digital Video Compression, Motion Estimation, Multi Resolution Discrete Wavelet Transform (MRDWT), Adaptive Road Search Pattern (ARSP)**,** Compression Ratio (CR).

الخلاصة

في هذا البحث، تم تقديم مقترح لنظامَ معتمد لضغطِ الفيديو الرقميِ. في هذا النظامِ تم حل مشكلةَ تغييرَ الترحيفَ التي تنشأُ بسبب تخمينِ الحركة وتعويضِها وَالناجمة من استعمال التحويل المويجي المتقطع لضغطِ المجالِ ألحيزي والحز مي. في هذا النظامِ، الفيديو الرقمي يُدْخَلُ إلى العمليتين الرئيسيتينِ، أولاً تطابق الصورة لرصد الحركة وتقليل الفائضية الوقتية، والثانية التحليل المتعدّد الدقة للتحويل المويجي المتقطع لكشفِ الفائضيةِ الحيزيةِ والحزمية، ثمّ يدخل نتيجة التحليلِ إلى عملية التحديد ذات المستويات المتعددة الطاقة قبل دُخُولها إلى عملية التشفير حسب كمية المعلومات. النظام المُقتَرَح نُفّذَ على نظامِ ضغطِ الفيديو التقليدي وأقترح نظامَ ضغطِ فيديو أخر. العديد مِنْ أفلامِ الفيديو الرقميةِ ذات الحركاتِ المختلفةِ (بسيطة، معقدة) أاستعملت في إختبار النظامين وتم مقارنة النَتائِجِ من حيث نسبةِ الضغطِ ، نوعية الفيديو الناتج بعد عملية الضغطِ ، ووقت المعالجة المطلوبةِ. كُلّ البرامج والرُسومات تم تنفيذها باستخدام برنامج MATLAB نسخةِ R2008a.

1-Introduction

By nature of video data are large in size and eventually require huge storage space and excessive time to process and transmit, compression techniques can over come these difficulties, therefore, compression techniques remain an active field for researchers working in video/image processing.

The Discrete cosine transform (DCT) was used as a method of video compression. This is done by decomposing the frames into components of different spatial frequencies. The method showed compression performance with various MPEG implementations [Marc Servais et al, 1999]. Motion estimation plays an important role for the compression of video signals. Motion estimation for video compression using Kalman filtering was presented in [Chung-Ming Kuo et al, 1996]. The method utilizes the predicted motion and measured motion to obtain an optimal estimate of motion vector.

Some motion estimation algorithms require great amount of computations. A Fast full search motion estimation algorithm was investigated in [Jong-Nam,Kim et al, 2001]. It utilizes a faster elimination of inappropriate motion vectors using efficient matching units from localization of the complex area in image data. A method named as Modified Orthogonal Search Algorithm (MOSA) for the block based motion estimation presented in paper [Shilpa P. Metkar et al, 2009]. The paper introduces the center biased search point pattern for the estimation of small motions and a half way stops technique to reduce the computational complexity. The wavelet transform decomposes a non-stationary signal into a set of multi-resolution wavelet coefficients where each component becomes relatively more stationary and hence easier to code [Hyun Wook Park et al, 2000]. Video compression using adaptive quantization was presented, wavelet transform is applied and the resulting bands were adaptively quantized reducing quality [Aree A Mohammed et al, 2008].

Dual wavelet based video compression was investigated in [Unan Yusmaniar Oktiawati et al, 2007]. Initial results shows that dual tree complex wavelet transforms yield improved Peak Signal to Noise Ratio compared to discrete wavelet and discrete cosine transform. Many researchers investigated the motion estimation technique in wavelet domain to reduce temporal redundancy [Hyun Wook Park et al, 2000]. The technique used in the wavelet domain is low band shift method to overcome the shift variant property. The method has a superior performance to the conventional motion estimation methods in terms of the mean absolute difference (MAD). The important problem in video compression is the processing time that taken by motion estimation search algorithm. This problem became less than after appearance of Adaptive Road Pattern Search (ARPS) for fast block matching motion estimation [Yao Nie et al, 2002].

In this work a new method of digital video compression is presented. The method states to use two dimensional multi-resolution discrete wavelet transform (2D-MRDWT), proposed quantization for the elimination of the spatial and band redundancy and ARPS for motion estimation to eliminate the temporal redundancy. The research is interest in required processing time for execution, peak signal to noise ratio, and compression ratio. The proposed system tests two methods, first with conventional video compression system and the second with the proposed method for video compression. The second method avoids the system from the shift variant in motion estimation and compensation because of using wavelet transform in spatial compression that was processed in reference [Unan Yusmaniar Oktiawati et al, 2007] by using dual complex discrete wavelet transform
(DCDWT). This method requires processing time high greater from the conventional DWT; therefore, the advantage of the proposed system is low processing time as well as other parameters such as compression ratio and peak signal to noise ratio.

2- The Video Compression Using Mrdwt

The discrete wavelet transform executes a decomposition of video frames or motion compensated residuals to a multi-resolution subband representation. The use of the discrete wavelet transform has become a vital role in image and video compression due to its easy implementation and reduced computation time and resources.

The signal to be analyzed is passed through different cut off frequency filters at different scales. The 2D DWT decomposition is achieved by applying the 1D transform in the horizontal and vertical directions as shown in **Figure (1-a))**[N.Venkateswaran et al, 2007]. The outputs LL, LH, HL, and HH are sub-band images. LL is the lowest sub-band image and it represents a smaller low-resolution version of the original image, it is also called "Approximation". The other sub-band images LH, HL, and HH are high-pass samples and they represent a smaller residual version of the original image they are called "Details"[N.Venkateswaran et al,2007]. In MRDWT the above process is repeated for the LL matrix and continued until the desired level of decomposition [Antonini M et al, 1992]. The process of decomposition was gave large numbers of zeros in the output coefficients. The zeros help in image coding and called zero tree coding [S. Radhakarishnan et al, 2009] and these zeros may be increases by increasing the decomposition levels.

The decompressed or reconstructed image could be reconstructed by recombined the sub-band images are in the reconstruction stage so that the original image can be reconstructed. The reconstruction process of 1-level DWT is depicted in **Figure (1-b)**[N.Venkateswaran et al, 2007]. Because of the DWT decomposition and decomposition are inversely process the original image may be reconstructed; this type of compression called lossless compression and if some thresholds or quantization used the reconstructed image is an approximation to the original.

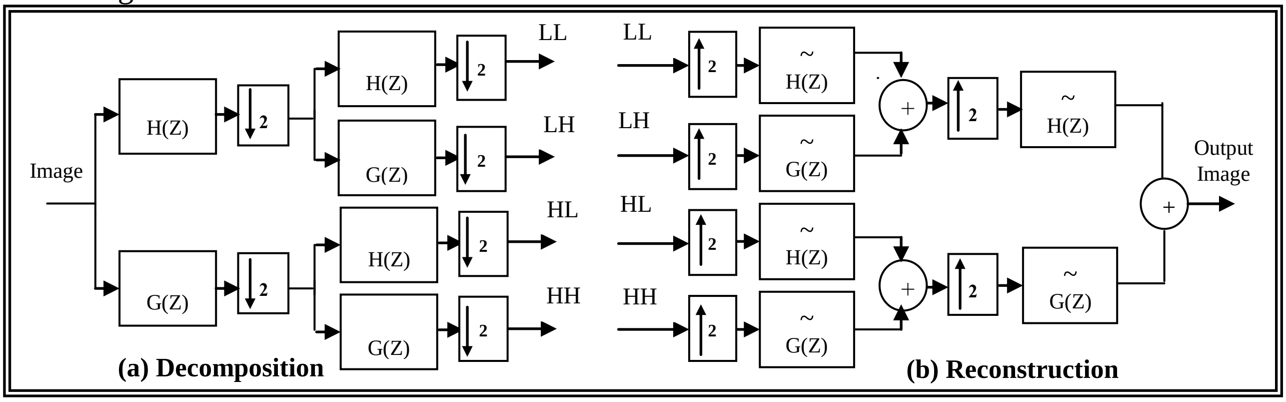


Figure (1): One Level DWT Decomposition and Reconstruction

3- Motion Estimation And Compensation

Motion estimation forms a model of the current frame based on available data in one or more previously encoded reference frames with acceptable computational complexity. The model takes advantage of the strong correlation between frame to frame along the temporal dimension. It divides the frame into blocks; each block is matched with a reference frame. The matching between macro blocks depends on the output of a cost function. The macro block that has less cost output is the closest to current macro block. Two dimension vectors represent the estimated motion which is known as" Motion Vectors" [Ala'a Basil Hussain, 2009].

Matching criterion can be used to obtain motion vectors between one macro block and another. There are many types of cost functions, one of the most popular and less computational complexity is Mean Squared Error (MSE) given by equation (1)[Wafaa Hassan Al-Marsomi 2006]. Another type of cost function is Mean Absolute Difference (MAD) given by (2)[Wafaa Hassan Al-Marsomi 2006].

$$\text{MAS}=1/(\text{N*M})\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(C_{ij}-R_{ij}\right)^2 \qquad (1)$$

$$\text{MAD}=1/(\text{N*M})\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left|Cij-Rij\right| \qquad (2)$$

Where N and M are the sides of the macro block, C_{ij} and R_{ij} are the pixels being compared in current and reference macro block respectively.

There are two main techniques of estimation of motion vectors: Pel-Recursive Algorithm (PRA) and block –Matching Algorithm (BMA) Block matching Algorithms are suitable and simple. The simplest Block matching algorithms is known as full search, but it has great computational operations in software implementation, more than the remaining components of the encoder. Other algorithms have reduced the number of searches but these algorithms can get trapped into local minimum matching error points, namely ,three step search [Renxiang Li et al, 1994] and the four step search [Lai-ManPo et al,1996]. Adaptive Road Pattern Search is used in this work to overcome this problem. The motion compensation uses the motion vectors to obtain a frame of a movie. Each block is predicted from a block that has an equal size in the reference frame using the motion vectors computed from the motion estimation.

4- Adaptive Road Search Algorithm

This algorithm is a type of block matching algorithm. The main principle of this algorithm depends on the similarity of motion between the current macro block and the motion of the macro blocks around it (belonging to the same moving object), as a result, the current macro block's motion vector can be predicted [Yao Nie et al, 1996]. The road pattern is formed of four vertexes and is symmetrical the step size (SS) which is the distance between the vertex and the center is given by(3) [Yao Nie et al, 1996]:

$$SS = \sqrt{\vec{H} + \vec{V}} \qquad (3)$$

Where:

$\vec{H}$: is the horizontal coordinate.

$\vec{V}$: is the vertical coordinate.

Motion vectors of a current macro block is predicted (or calculated) from the motion vectors of the direct left, with respect to the current block. The search pattern consists of two sequential search stages: first; initial search and second; refined local search [adaptive road pattern search for fast block matching]. The road pattern can detect the point that has the least weight by leaping to that point. The point will become the center of other following searches. The point which has minimum matching error will be a start for a new search. A fixed and small search is used to carry the local refined search is used. The small search is using the diamond search [Joseph Yeh et al, 1995]. In an advantage of reducing computational complex, the algorithm use zero-motion prejudgment. This is accomplished if the point which posses less weight is at the center.

5- Proposed Video Compression And Decompression System

The compression system in general includes two main parts, the first part is concerned with spatial and band redundancy removing and the second part is concerned with motion estimation or temporal redundancy removing. The first part compresses each video frame by using MRDWT. The color video frame or image is segmented to three RGB layers and each layer (in gray scale) is processed individually. The 2-D layer is decomposed by using L-level of 2-D MRDWT there will be four output matrices from each level of DWT, one matrix represents the approximation coefficients and the others represent the detail coefficients matrices. The most information about the image or matrix exists in approximation coefficients while the other coefficients contains on most spatial and band domain redundancy. The decomposition continued for each approximation coefficients until L-level. In each decomposition a number of zeros are produced and then choose hard; soft; or universal threshold for the details coefficients only and keep the approximation coefficients with out any change (equation 4)[Kamrul Hasan Talukder et al, 2007] to obtain the largest possible number of zeros without destroying the original image in decompression process.

$$T(\varepsilon,x)=\begin{cases} 0, & \text{If } |x|<\varepsilon \\ x, & \text{otherwise} \end{cases} \qquad \textbf{(Hard Threshold)}$$

$$T(\varepsilon,x)=\begin{cases} 0, & \text{If } |x|<\varepsilon \\ Sign(x)(|x|-\varepsilon), & \text{otherwise} \end{cases} \quad \textbf{(Soft Threshold)} \qquad (4)$$

$$T(\varepsilon,x)=\begin{cases} 0, & \text{If } x<\sigma(2\log_2 N)^{1/2} \\ x, & \text{otherwise} \end{cases} \quad \textbf{(Universal Threshold)}$$

Where ε is the value of threshold and *x* is the value of pixel in details coefficients. In this work we used different values of thresholds for different levels because the redundancy reduced in each level therefore the value of threshold must be reduced for each level to keep on the quality of the decompressed frame. After the above process, all the produced coefficients enters the proposed quantization. The quantization stage compute the mean of each subgroup of MRDWT decomposition after thresholding process then product the result by a ratio such as (0.3, 0.5, 0.6, …etc) to limit the step-size with respect to mean value of sub-group for the levels of quantization, then take integer division for each pixel on the step-size and multiply by the step size to obtain the output of the quantization stage. The output of this stage will give large similarity in sub group coefficients, this will reduce the number of bits or the memory size required in entropy encoder.

The last stage in the spatial compressor algorithm is the entropy encoder. In this work the entropy encoder is the run length encoding (RLE). The output data from the quantization stage of each frame is arranged in one vector and encoded using the lossless RLE that store each element in the vector and its sequential repetition. The decompression part for spatial domain consist of run length decoding (RLD) stage to obtain on a vector of data represent the information of compressed frame then convert this vector to sub-group matrices for each layer to enter the DWT reconstruction of L-level then arranging 3-D matrix of reconstructed layers to build the decompressed frame.

The motion estimation part compare between previous and current frame to estimate the motion vector using adaptive road search (ARS) and store the delta information between the current frame and reference frame. In Decompression side the motion compensation between the previous and current decompressed frame achieved to reconstruct all the video scene frames.

The proposed video compression and decompression system is built by using two methods; the first method is using the proposed algorithm inside the conventional block diagram of video compression shown in **Figure 2**. The second method is a proposed block diagram for video compression by postponing the motion estimation between the frames after the spatial compression process completely. The compression system according to the second method that is shown in **Figure 3** satisfy better results from the first system in processing time, compression ratio, and in quality of decompressed video. The important disadvantage with using DWT in video compression is that it is shift-variant and it cannot directly be used for motion estimation as like in **Figure 2** because some distortion appears in some reconstructed compressed video frames. Reference [Unan Yusmaniar Oktiawati et al, 2007] suggests using dual tree complex wavelet transform to solve part of this problem. The method succeeds in solve the problem but increases the processing time because of the increasing computational process in this method. In this work, we solve both problems shift-variant and processing time by using the proposed system shown in **Figure 3.**

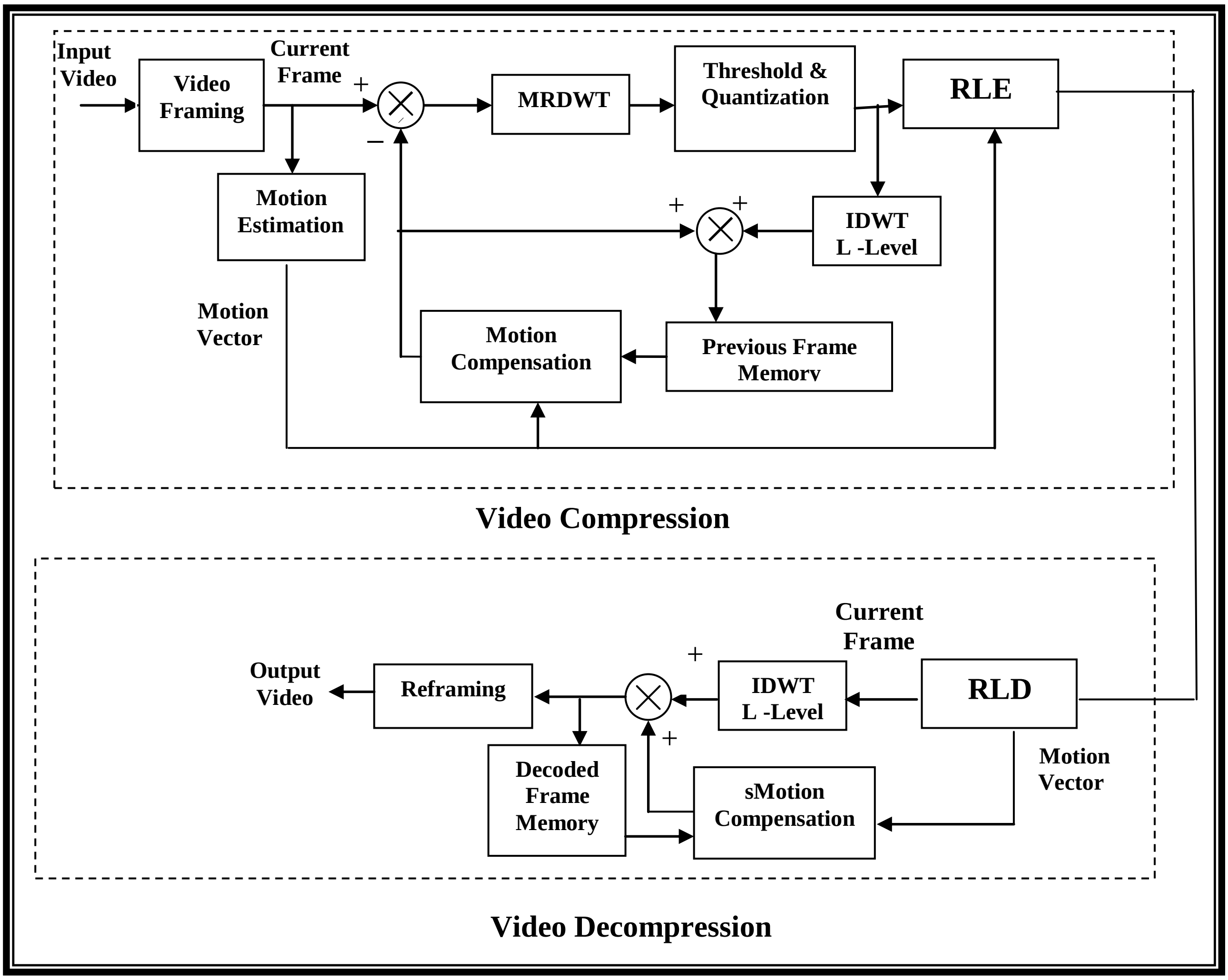


Figure (2): The Proposed System inside Conventional Block of Video Compression and Decompression

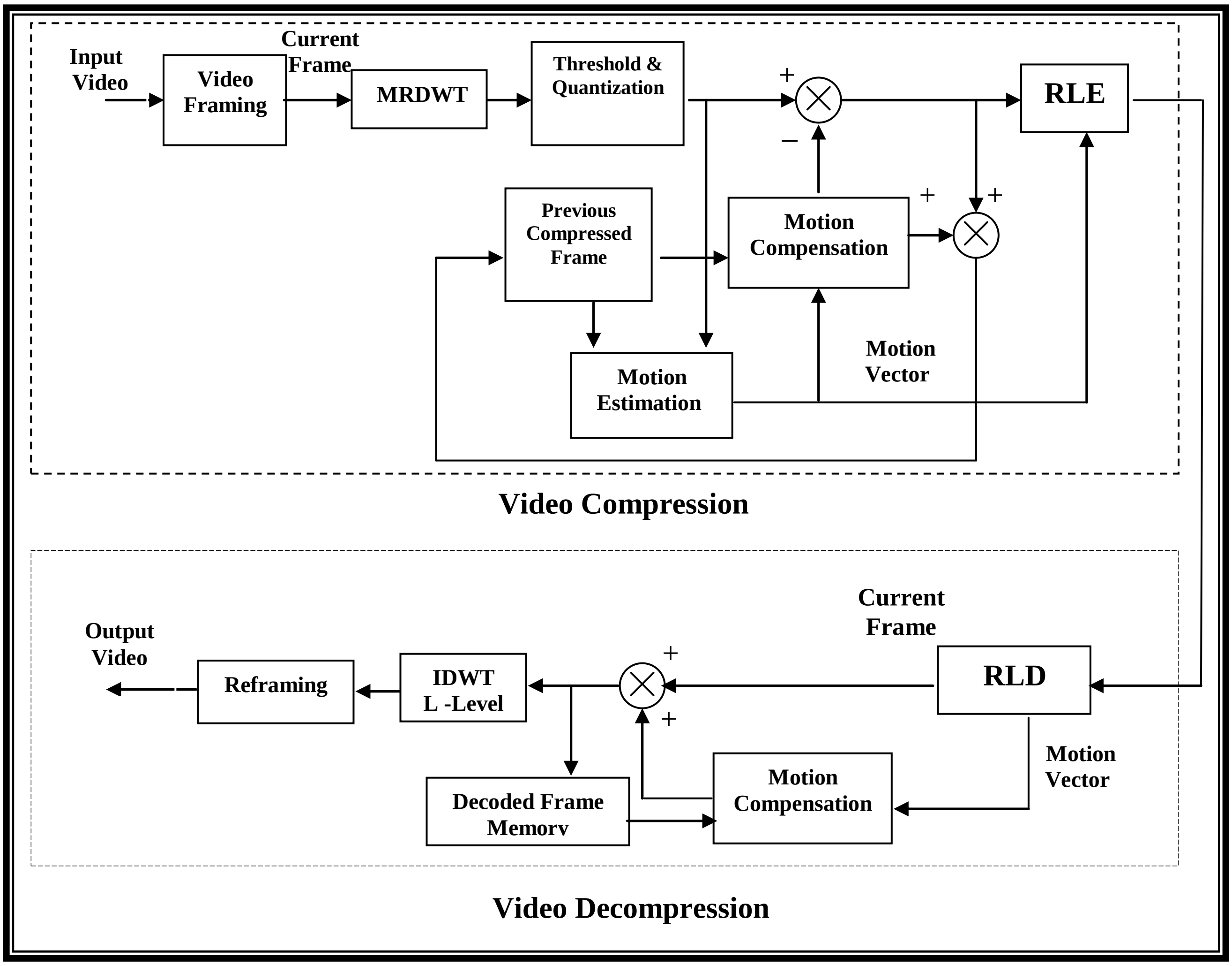


Figure (3): The Proposed Video Compression and Decompression System

6- Results And Discussion

The results of the two proposed systems are compared according to compression ratio (CR), Peak signal to noise ratio (PSNR) and execution time. The results are illustrated in the tables and curves below, All the required programs and graphs are executed using Matlab version R2008a on a dual core 768MHZ RAM Pentium IV computer. At first, we must set the parameters for the systems throughout the experiments. In the experiments below we use two level DWT decomposition and Haar type filter. The type of search used regarding the motion estimation is the adaptive road search. The systems would be tested by three videos has first and twenty sixth frames as shown in **Figure 4** which contain different types of motion. The sizes of the frames are (240*360*3) with macro block search size of (4*6) for the first video and (240*320*3) with macro block search size of (4*4) for the other two videos. Each one of three videos entered to the two systems, for the first system the video framing to constant images and each image goes to the motion estimation part and to the spatial compressor part after the delta operation between the current and previous frames achieved. The compression ratio (**CR**) of compression depends on the values of thresholds that are used after DWT decomposition and the step size (**SS**) of the quantization stage. In this example many values used for hard threshold as shown in **Tables 1-3**. In each experiment there are two thresholds, one for the first level details coefficients (**ε_1**) and the second for the details coefficients of the second level (**ε_2**). For the second compression system or proposed compression system the same values of hard thresholds applied and compared in each case that shows in **Tables 1-3**. The first and twenty sixth frames of decompressed videos in each case of thresholds for the two systems and the curves which illustrate the relationship between (**CR**) for the two systems and their frames are shown in **Figures 11-13**. In each table we list the average compression Ratio (**ACR)** for all video frames and average peak signal to noise ratio (**APSNR**) for all decompressed frames for each video, as well as the processing time **(PT**) required for compression process. In **Figures 5-7**, we see some distortion in the reconstructed frames. The reason of this distortion is the shift variant that is accumulated along the estimation process and appears in the reconstructed frames after compensation process. On the other hand, the **Figures 8-10** represent the reconstructed frames by using the proposed compression system which does not have any distortion and this indicates that the system has put an end to the shift variant problem because of using DWT. By comparing the **Tables 1-3** with **Tables 4-6** we see significant decreasing in processing time, increasing in compression ratio and high peak signal to noise ratio. The **Figures 11-13** compares the compression ratios of each frame for each video that is entered to the two systems.

7-Conclusion:

In this paper a video compression system is presented, the results which are presented show that the proposed system yields better visual results, high compression ratio and less processing time compared to those obtained from the system inside conventional system. The results also show improved PSNR. In the proposed system the shift variant problem was cured which was produced as a result of motion estimation and compensation linked by using DWT.

Frame 1

Frame 1

Frame 1

Frame 26

(a) Viplanedeparture

Frame 26

(b) Rhinos

Frame 26

(c) Vipmosaicking

Figure (4): First and Twenty sixth Frames from the Original Videos

Table (1): First Experiment of the Conventional System (Shown in Figure 2) with Thresholds (ε_1 = 30, ε_2 = 15, SS = 0.33)

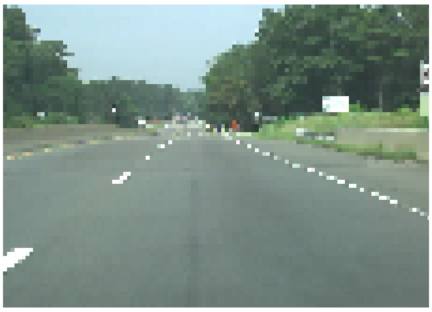
Video Number	Video Name	APSNR	ACR	PT
1.	Viplanedeparture	31.3862 db	69.65 %	1225 sec
2.	Rhinos	21.5838 db	67.82 %	958 sec
3.	Vipmosaicking	22.7210 db	65.44 %	1090 sec

Table (2): Second Experiment of the Conventional System (Shown in Figure 2) with Thresholds (ε_1 = 50, ε_2 = 30, SS= 0.5)

Video Number	Video Name	APSNR	ACR	PT
1.	Viplanedeparture	29.1923 db	78.96 %	876 sec
2.	Rhinos	21.4533 db	78.36 %	707 sec
3.	Vipmosaicking	22.2393 db	77.03 %	865 sec

Table (3): Third Experiment of the Conventional System (Shown in Figure 2) with Thresholds (ε_1 = 200, ε_2 = 30, SS= 0.33)

Video Number	Video Name	APSNR	ACR	PT
1.	Viplanedeparture	25.1568 db	87.73 %	760 sec
2.	Rhinos	21.0126 db	87.60 %	695 sec
3.	Vipmosaicking	20.8899 db	87.46 %	660 sec



Reconstruct First Frame

Reconstruct First Frame

Reconstruct First Frame

Reconstruct 26th Frame

(a) Viplanedeparture

Reconstruct 26th Frame

(b) Rhinos

Reconstruct 26th Frame

(c) Vipmosaicking

Figure (5): The Reconstructed Selected Frames Referred to First Experiment Shown in Table 1

Reconstruct First Frame

Reconstruct First Frame

Reconstruct First Frame

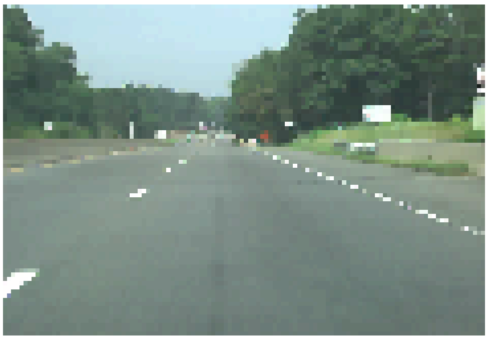
Reconstruct 26th Frame

Reconstruct 26th Frame

Reconstruct 26th Frame

(a) Viplanedeparture **(b) Rhinos** **(c) Vipmosaicking**

Figure (6): The Reconstructed Selected Frames Referred to Second Experiment Shown in Table 2



Reconstruct First Frame

Reconstruct First Frame

Reconstruct First Frame

Reconstruct 26th Frame

(a) Viplanedeparture

Reconstruct 26th Frame

(b) Rhinos

Reconstruct 26th Frame

(c) Vipmosaicking

Figure (7): The Reconstructed Selected Frames Referred to Third Experiment Shown in Table 3

Table (4): First Experiment of the Proposed System (Shown in Figure 3) with Thresholds ($\varepsilon_1 = 30$, $\varepsilon_2 = 15$, SS = 0.33)

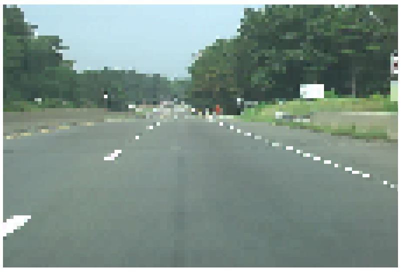
Video Number	Video Name	APSNR	ACR	PT
1.	Viplanebdeparture	34.7773 db	83.01 %	235 sec
2.	Rhinos	35.3459 db	82.56 %	251 sec
3.	Vipmosaicking	34.4620 db	83.56 %	143 sec

Table (5): Second Experiment of the Proposed System (Shown in Figure 3) with Thresholds ($\varepsilon_1 = 50$, $\varepsilon_2 = 30$, SS= 0.5)

Video Number	Video Name	APSNR	ACR	PT
1.	Viplanedeparture	32.1565 db	90.07%	94 sec
2.	Rhinos	32.2565 db	89.29%	92 sec
3.	Vipmosaicking	31.0812 db	89.89 %	105 sec

Table (6): Third Experiment of the Proposed System (Shown in Figure 3) with Thresholds ($\varepsilon_1 = 200$, $\varepsilon_2 = 30$, SS= 0.33)

Video Number	Video Name	PSNR in dB	ACR	Compression Time
1.	Viplanedeparture	27.3516	93.93%	71sec
2.	Rhinos	27.3516	93.86%	75sec
3.	Vipmosaicking	26.0883	93.54%	74sec



Reconstruct First Frame

Reconstruct First Frame

Reconstruct First Frame

Reconstruct 26th Frame

(a) Viplanedeparture

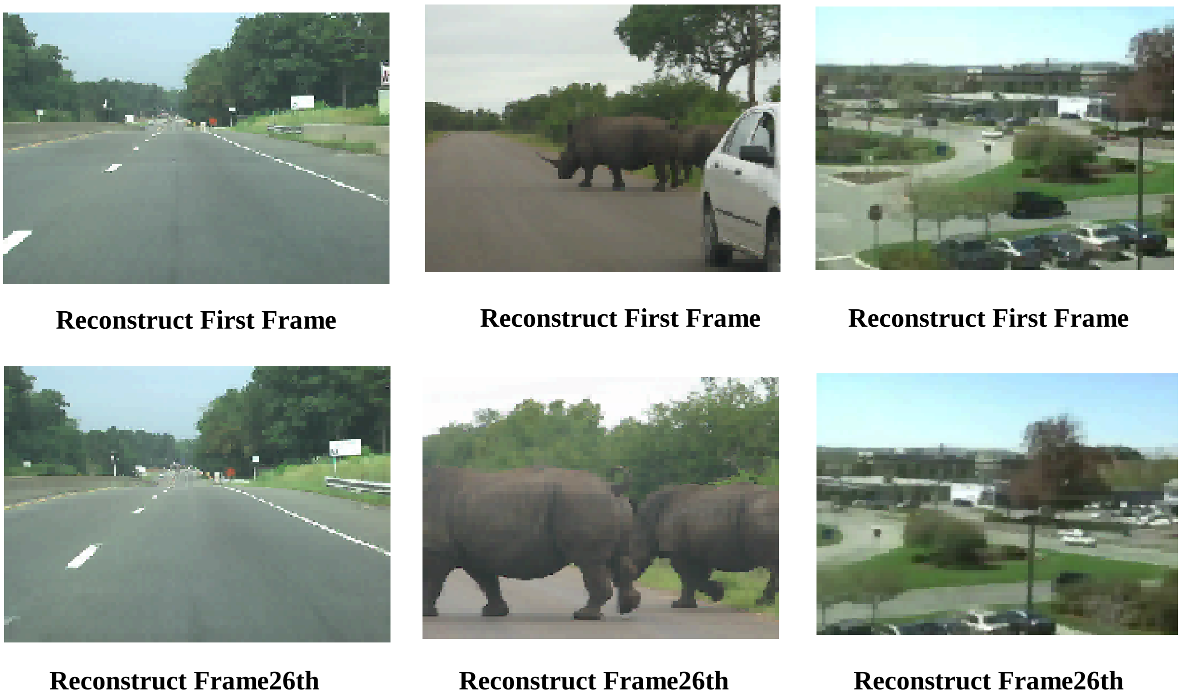
Reconstruct 26th Frame

(b) Rhinos

Reconstruct 26th Frame

(c) Vipmosaicking

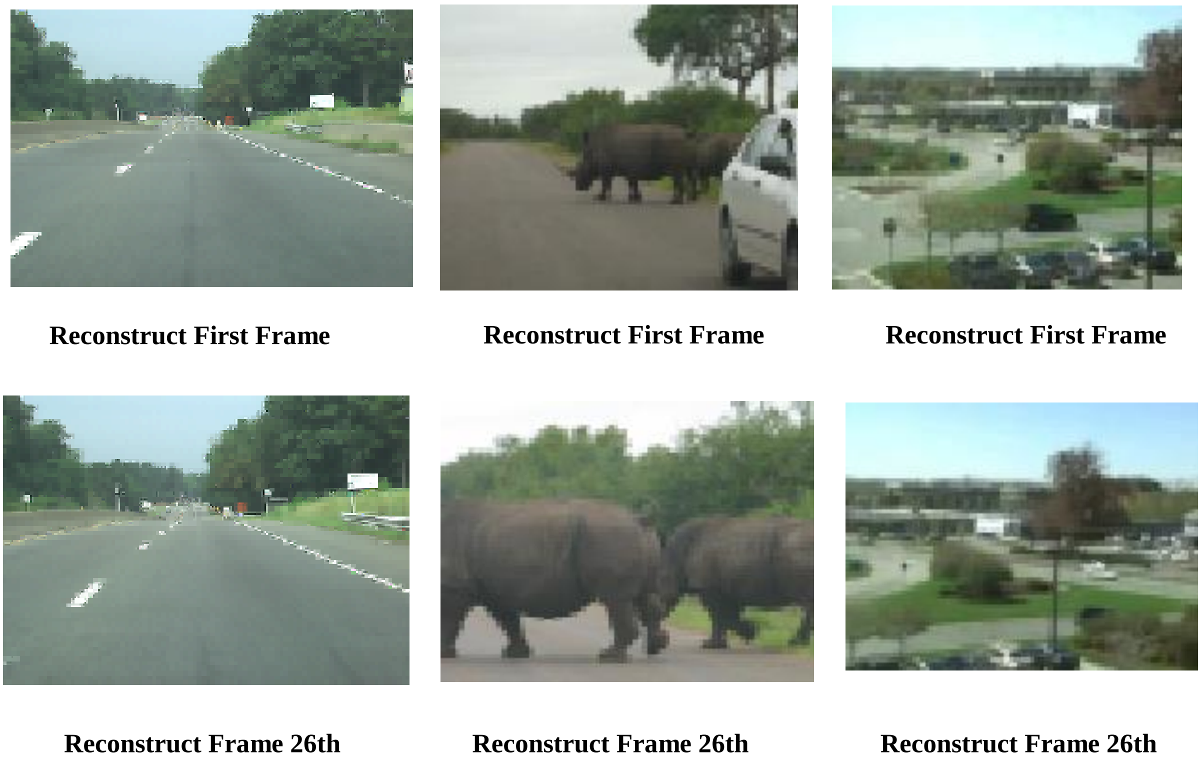
Figure (8): The Reconstructed Selected Frames Referred to First Experiment Shown in Table 4



Reconstruct First Frame | Reconstruct First Frame | Reconstruct First Frame

Reconstruct Frame26th | Reconstruct Frame26th | Reconstruct Frame26th

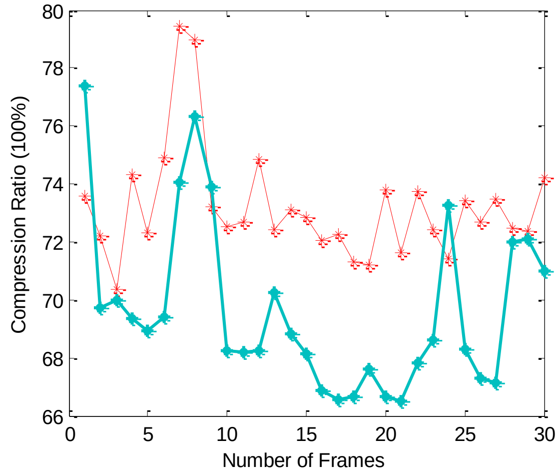
Figure (9): The Reconstructed Selected Frames Referred to First Experiment Shown in Table 5



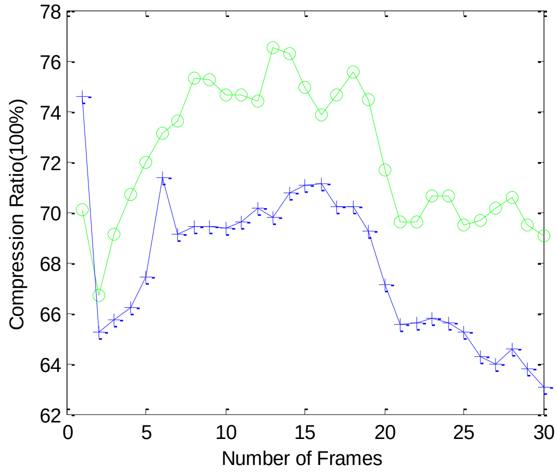
Reconstruct First Frame | Reconstruct First Frame | Reconstruct First Frame

Reconstruct Frame 26th | Reconstruct Frame 26th | Reconstruct Frame 26th

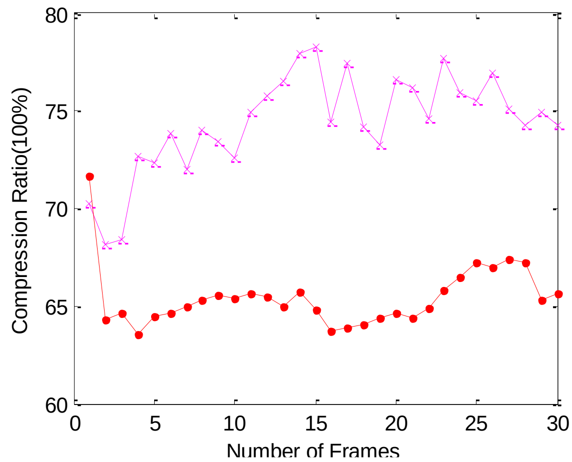
Figure (10): The Reconstructed Selected Frames Referred to First Experiment Shown in Table 6



a. Crayon: Conventional System& Red for Proposed system

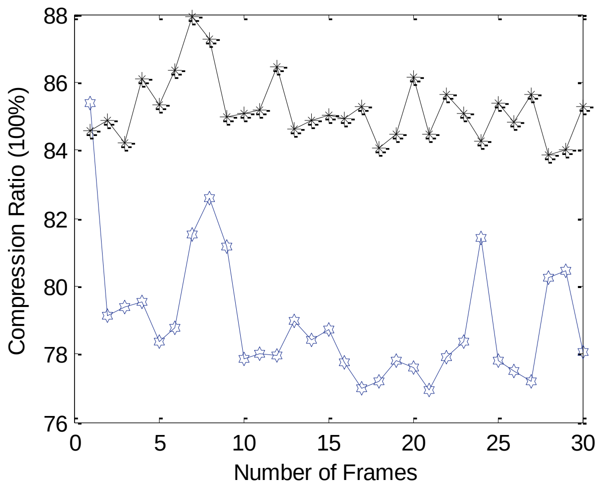


b. Blue: Conventional System& Green: Proposed system

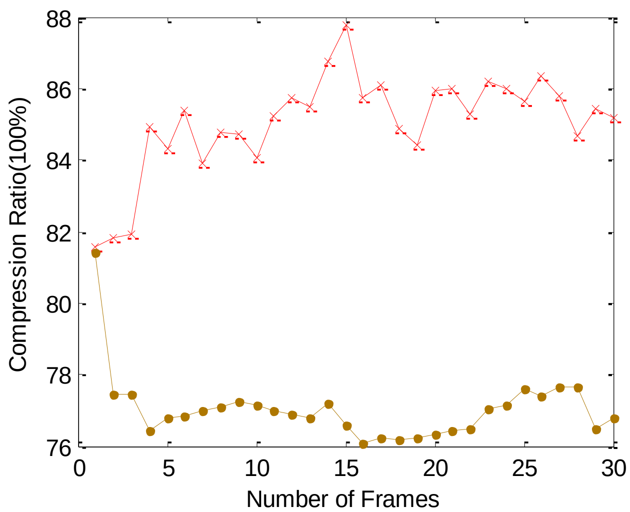


c. Red: Conventional System& purple: Proposed system

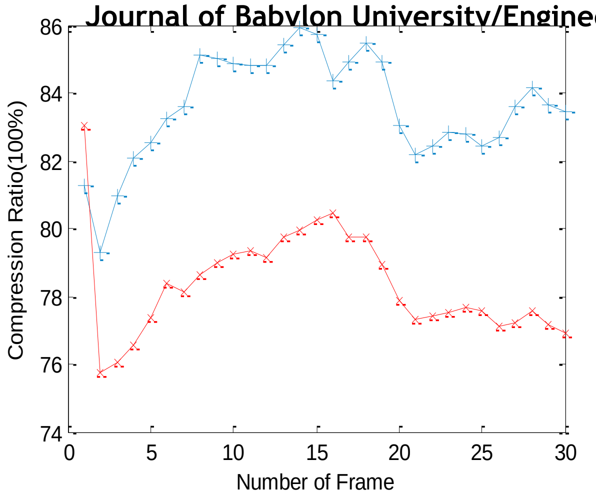
Figure .11 , CR for each Frame for each video movie with Thresholds ($\varepsilon_1 = 30$, $\varepsilon_2 = 15$, SS = 0. 33)



a. Blue: Conventional System& Black: Proposed system

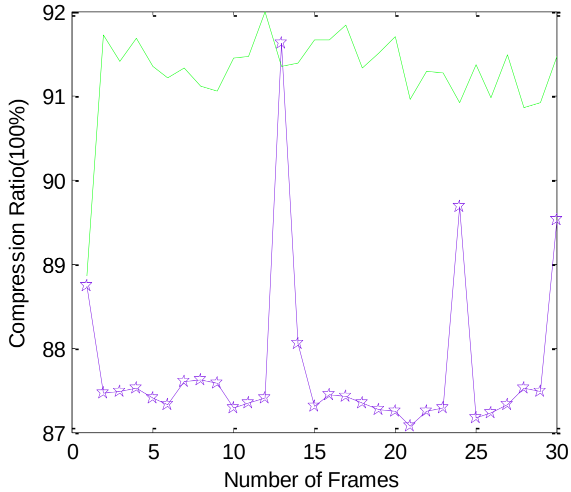


b. Red: Conventional System& Brown: Proposed system

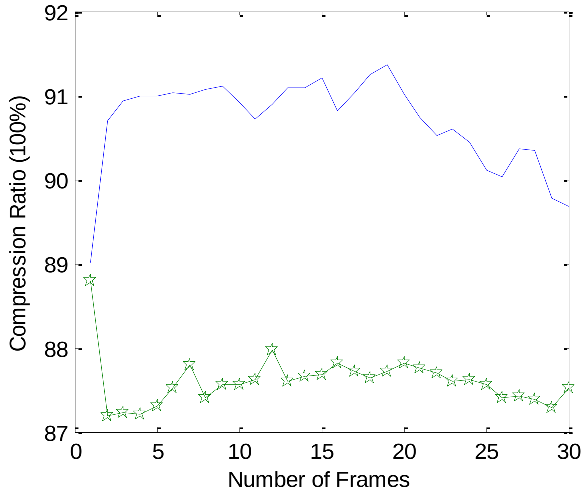


c. Red: Conventional System& Porpoal: Proposed system

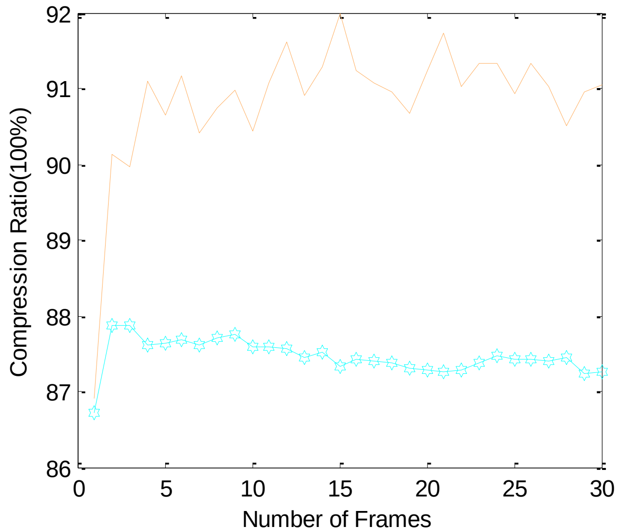
Figure .12 , CR for each Frame for each Video movie with Thresholds (ε1 = 50, ε2 = 30, SS= 0. 5)



a. Blue: Conventional System& Green: Proposed system



b. Red: Conventional System& Black: Proposed system



c. Crayon: Conventional System& Orange: Proposed system

Figure .13 , CR for each Frame for each Video movie with Thresholds ($\varepsilon_1 = 200$, $\varepsilon_2 = 30$, SS= 0. 33)

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