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Spatial and Temporal DWT Multi Resolution Analysis on Video Encoding Mechanisms

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ABSTRACT

In this paper we are going to discuss about the application of Spatial and Temporal Discrete Wavelet transform (DWT) on to the videos. Here we are going to compare the spatio-temporal 3D-DWT multi resolution analysis with temporo-spatial 3D-DWT multi resolution analysis (MRA). We compare them based on their performance by taking the system memory utilization and the time taken for encoding and decoding the video. Here, we are going to generate MRA on frames in temporal axis and also in each frame in spatial axis, thus we generate the 3D-MRA using spatio-temporal and temporo-spatial DWT. In this paper, Haar wavelet is taken as the due to its ease of implementation and inherent properties.

***Index Terms*-- DWT, spatio-temporal DWT, temporo-spatial DWT, MRA, Haar Wavelet.**

I.INTRODUCTION

In this paper we are going to study and compare spatio-temporal 3D-DWT MRA [1,2] with temporo-spatial DWT MRA [4] with respect to the metrics i.e., time taken for encoding the video, time taken for decoding the video, and system memory utilized when performing the operations on the given video sequence. we had chosen the time for processing and system memory as our metrics for comparison in this paper because, time for processing and memory are the two vital parameters to look upon in any video processing algorithm. In any video processing algorithm, it is expected that the processing time of the algorithm and the memory utilization need to be as low as possible. This reduction in both parameters will make the application as real time application and also the hardware cost and complexity of the processing unit will be less. If any of these parameters shoots up then it degrades efficiency of the video processing algorithm. Spatio-temporal DWT and temporo-spatial DWT are applied on to videos before and after compression due to its inherent properties of generating the zero trees, which is the basic concept fundamental the compression techniques such as EZW and SPIHT. So, these mechanisms can also be termed as pre and/or post processing techniques for compressing the video. In the proposed work, to apply DWT Haar wavelet [8] is taken as reference due to its inherent properties and ease of implementation. For applying the DWT the filter banks used are listed in table-I.

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TABLE I

Parameter	Forward DWT	Reverse DWT
Low pass mask	[1/2, 1/2]	[1,1]
High pass mask	[1/2, -1/2]	[-1,1]

By using the filter bank shown in table-I application of 2D Haar wavelet on images leads to four outputs namely LL, LH, HL and HH as shown in figure-1.

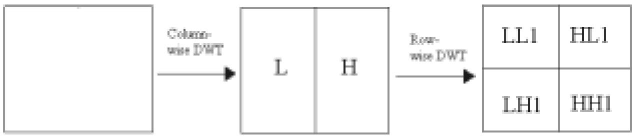

Fig.1: First level 2D-DWT generating four different outputs.

Application of this on low pass components leads to multi-level DWT and effectively multi resolution analysis (MRA) [1,3] as shown in figure (2) which will be discussed in section-II.

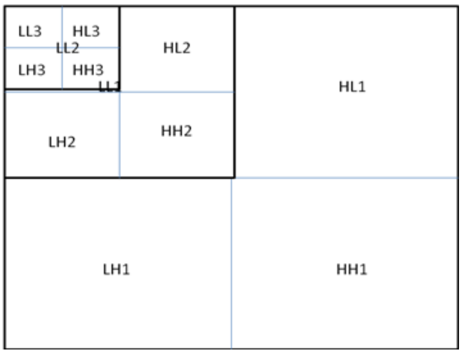

Fig. 2: Multi level Haar DWT decomposition of images

In section-III and section-IV we are going to discuss about spatio-temporal 3D-DWT [2, 6, 7] MRA and temporo-spatial 3D-DWT MRA respectively which generates 3D-MRA [5] based on the concepts of spatial and temporal DWT. In section-V comparison of the mechanisms is presented along with simulation results in section-VI and finally we conclude our work in section-VII.

II.MULTI RESOLUTION ANALYSIS

The wavelet analysis can often be called as Multi-Resolution Analysis (MRA) because in wavelet analysis one can observe that the low pass component which is generated in level-1 has size which is one fourth of the original and if we go on increasing the DWT levels one can observe that for increase in each level of DWT size of the low pass component decrease by one fourth. This property of wavelet generates the multi-resolution analysis as shown in figure-3 on 2-D data such as images.

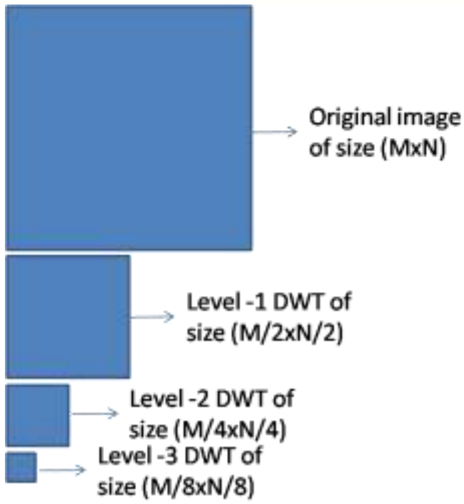

Fig. 3: Representation of MRA using wavelet analysis

Figure (3) only represents 2D MRA which can be applied on images, but to have a 3D-MRA one need to apply the same phenomenon on the temporal axis i.e., on frames. So, one can define 3D-MRA as the combination of 2D-MRA on frames and 2D-MRA in each frame. So, to generate 3D-MRA we need to apply Haar wavelet on each frame as shown above and along with that we need to apply it on frames in temporal axis also, which can be easily visualized using the spatio-temporal DWT and temporo-spatial DWT which will be discussed in the later sections.

III.SPATIO-TEMPORAL 3D-DWT MRA

Spatio-temporal 3D-DWT MRA can be generated by applying the spatial and temporal DWT simultaneously on the combined low pass outputs of the video. The steps to be followed for generating the spatio-temporal 3D-DWT are listed below:

1. Apply the spatial DWT (2D-DWT) of level-1 on each frame of the video.
2. On the output generated by the step-1 apply temporal DWT (1D-DWT) of level-1. After this step, low pass output of the video occupies one fourth of the previous size.
3. Now, the low pass output generated in step-2 is the input for second level spatial DWT. Now, the low pass components generated by spatial DWT are given as input for second level temporal DWT and so on.

One can repeat these steps until number of rows or number of columns or number of frames reaches an odd number or 'one'. This generates 3D-MRA. As we are generating the 3D-MRA by applying the spatial DWT initially, this can be called as spatio-temporal 3D-DWT MRA. The diagrammatical representation of spatio-temporal 3D-DWT MRA is shown in figure (4). In figure (4) LT, HT corresponds to low pass temporal and high pass temporal of corresponding level respectively. 2 to 4 represents high pass of level-1 spatial DWT, 6 to 8 represent high pass of level-2 spatial DWT, 10 to 12 represent high pass of level-3 spatial DWT, and 9 represents all low pass component.

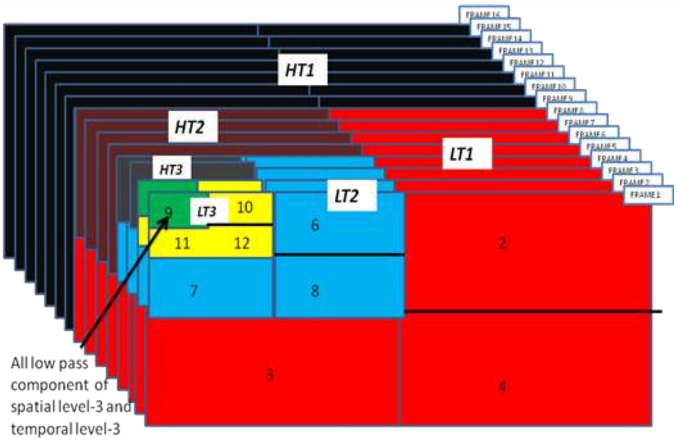

Fig. 4: Diagrammatical representation of spatio-temporal 3D-DWT MRA

The mathematical representation formulation of generating the spatio-temporal MRA is explained in the next subsection.

A. **Mathematical expressions for generating the spatio-temporal DWT**:

Here we will discuss about the equations which help us in applying the K-level temporal DWT to the video. Here for explanation let us consider a video of size ‘**m**’ by ‘**n**’ by ‘**p**’.

1. **Encoding:**

$$(LP_x)_K = \sum_{i=1}^{\frac{m}{2^K}} \sum_{j=1}^{\frac{n}{2^K}} \frac{F(i,j,x)+F(i,j,x}{2} \qquad (1)$$

$$(LP_x)_K = \sum_{i=1}^{\frac{m}{2^K}} \sum_{j=1}^{\frac{n}{2^K}} \frac{F(i,j,x)+F(i,j,x}{2} \qquad (2)$$

Where,

‘K’ denotes the level of temporal DWT applied,

‘x’ denotes the frame number and its maximum value is $p/(2^K)$,

‘F’ denotes the frames of the original video.

2. **Decoding:**

$$(FP_x)_{K-1} = \begin{cases} \sum_{i=1}^{\frac{m}{2^K}} \sum_{j=1}^{\frac{n}{2^K}} (LP(i,j,\frac{x+1}{2}))_K + (HP(i,j,\frac{x+1}{2}))_K & , x \text{ is odd} \\ \sum_{i=1}^{\frac{m}{2^K}} \sum_{j=1}^{\frac{n}{2^K}} (LP(i,j,\frac{x}{2}))_K - (HP(i,j,\frac{x}{2}))_K & , x \text{ is even} \end{cases} \qquad (3)$$

Where,

‘K’ denotes the maximum level of the temporal DWT applied.

‘x’ denotes the frame number and its maximum value is $\frac{p}{(2^{K-1})}$

‘FP’ denotes the low pass frames of the previous level.

To get back the frames of previous temporal level i.e., (K-1)th level, one need to know the high pass and low pass component of the present level i.e., Kth level. So, to get back the original video one nedd to have to start solving from Kth level, one cannot directly calculate the frames of any intermmediate level without having the prior knowledge of the present temporal level.

From the equations and from the steps listed in section-III it is clear that here one is not using the entire video for the processing of the higher levels in spatial and temporal DWT. This helps us in utilizing the memory efficiently as we are not processing $1/4^{th}$ part of the frame and $1/2^{th}$ part of the frame (with respect to the current frame size and number of frames) for every increase in the DWT level at the time of encoding. So the memory utilization will reduce by almost $3/4^{th}$ when considered with the spatial DWT applied frame by frame and time consumption also reduces as we are computing less number of pixels in the increased level. In this way we can achieve the efficient utilization of the system memory and time requirement. Coming to the reconstruction, here also we are not utilizing the entire video at all levels. As we are approaching level-1 the usage of the system memory increases. So, at the time of reconstruction also one can achieve the efficient usage of system memory and time.

For a video of size 'm' by 'n' and with 'p' number of frames. For the level-1 spatial and level-1 temporal DWT we require m*n*p bytes of system memory for processing the video. Now, when we are going to level-2, high pass components are not considered so we require (m/2)*(n/2)*(p/2) bytes of system memory for processing the video and if we go to next level further the memory requirement will be reduced by a factor of 8 for every increment in the DWT level of spatial and temporal domain compared to the previous level.

IV.TEMPORO-SPATIAL 3D-DWT MRA

Temporo-spatial 3D-DWT MRA can be generated by applying the temporal and spatial DWT simultaneously on the low pass outputs of the combined results. The steps to generate the 3D-DWT MRA using temporo-spatial approach are listed below:

1. Apply the temporal DWT of level-1 on frame of the given video.
2. On the output generated by the step-1 apply spatial DWT of level-1. After this step, low pass output of the video occupies $\frac{1}{4}$ of the previous size.
3. Now, the low pass output generated in step-2 is the input for second level temporal DWT. Now, the low pass components generated by temporal DWT is given as input for second level spatial DWT and so on.

One can repeat these steps until number of rows or number of columns or number of frames reaches a odd number or 'one'. This generates 3D-MRA. As we are generating the 3D-MRA by applying the temporal DWT initially, this can be called as temporo-spatial 3D-DWT MRA. Diagrammatical representation of temporo-spatial 3D-DWT MRA is as shown in the figure (5).

In processing the video using the temporo-spatial 3D-DWT also helps in saving the system memory as we are not utilising the entire video for the higher levels of spatial or temporal DWT application.

The mathematical equations which are listed in the subsection A of section-III can be applied here to generate the 3D-MRA.

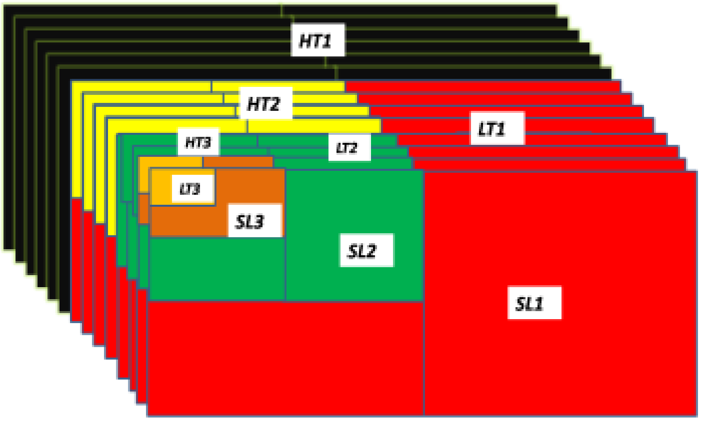

Fig. 5: Diagrammatical Representation of temporo-spatial 3D-DWT MRA.

Figure (4) and figure (5) visually may not make much difference between the spatio-temporal 3D-DWT and temporo-spatial 3D-DWT MRA analysis, but if we consider the time metric than it make a sense. So, now we will compare these mechanisms based on time in the next section i.e., section-V.

V.COMPARATIVE ANALYSIS OF SPATIO-TEMPORAL 3D-DWT MRA AND TEMPORO-SPATIAL 3D-DWT MRA.

These two mechanisms which are to be compared are tested on various standard videos, videos downloaded from the internet database and videos captured in the laboratory under non – standard conditions with a Canon Power shot A460 Digital camera having Approximately 5.3 Million Pixels 1/3.0 inch type CCD sensor with automatic exposure control and with video size of 480 by 640 pixels as given in table - 2. Video-1 is the standard video taken from MATLAB database, Video-2 is captured by us in the laboratory, and video 3 to video 8 are downloaded from the internet datasets [9, 10]. Here, we are presenting the comparison between the mechanisms, based on the time taken to transform and reconstruct the video in table 3 (for the level-1), in table 4 (for the level-2) and in table 4 (for the level-3). MSE is also calculated to represent the accuracy of the analysis done. As we are applying the spatial and temporal DWT simultaneously we cannot go for different levels of spatial and temporal DWT level.

TABLE II

VIDEOS LIST

Video Name	**Frame Size**	**No. of Frames/ sec (Frame Rate)**	**Video Duration (in sec)**	**Total number of frames**
Video 1	120x160	15	8	120
Video 2	480x640	10	13	128
Video 3	480x640	25	5	128
Video 4	480x640	25	10	250
Video 5	288x384	25	33	828

Video 6	480x640	25	8	196
Video 7	288x384	25	10	256
Video 8	288x384	25	21	512

TABLE III

COMPARISON OF SPATIO-TEMPORAL 3D-DWT AND TEMPORO-SPATIAL 3D-DWT FOR LEVEL 1

Video Name	***Time & MSER***	***Spatio-temporal***	***Temporo-spatial***
Video-1	DWT	0.152670	0.097485
	IDWT	0.134606	0.088081
	MSER	3.5290e-31	3.8812e-31
Video-2	DWT	2.381820	1.566822
	IDWT	2.055343	1.323571
	MSER	3.413763e-31	3.747079e-31
Video-3	DWT	2.426982	1.587923
	IDWT	1.965368	1.235588
	MSER	1.777797e-31	1.835746e-31
Video-4	DWT	4.795916	3.059824
	IDWT	4.579226	2.802846
	MSER	2.126812e-31	2.198491e-31
Video-5	DWT	5.894950	3.686158
	IDWT	5.004524	3.051750
	MSER	2.252974e-30	2.476354e-30
Video-6	DWT	4.253382	2.401310
	IDWT	3.223461	2.482818
	MSER	2.397394e-31	5.382606e-30
Video-7	DWT	1.801466	1.155306
	IDWT	1.526985	1.031005
	MSER	6.661259e-31	7.339305e-31
Video-8	DWT	3.619278	2.261268
	IDWT	3.064635	1.903497
	MSER	1.402898e-30	1.543767e-30

TABLE IV

COMPARISON OF SPATIO-TEMPORAL 3D-DWT AND TEMPORO-SPATIAL 3D-DWT FOR LEVEL 2

Video Name	***Time & MSER***	***Spatio-temporal***	***Temporo-spatial***

Video Name	*Time & MSER*	*Spatio-temporal*	*Temporo-spatial*
Video-1	DWT	0.188412	0.106091
	IDWT	0.149424	0.087730
	MSER	8.1044e-31	8.868227e-31
Video-2	DWT	2.841030	1.765081
	IDWT	2.324150	1.379318
	MSER	9.413107e-31	1.042262e-30
Video-3	DWT	2.802748	1.851705
	IDWT	2.269757	1.754088
	MSER	4.429887e-31	4.551301e-31
Video-4	DWT	NA	NA
	IDWT	NA	NA
	MSER	NA	NA
Video-5	DWT	7.009442	4.056143
	IDWT	5.586904	3.224071
	MSER	5.318898e-30	5.382606e-30
Video-6	DWT	4.521422	2.577001
	IDWT	3.785273	2.239773
	MSER	5.902504e-31	6.031220e-31
Video-7	DWT	2.112176	1.341926
	IDWT	1.711953	1.053528
	MSER	1.574587e-30	1.597078e-30
Video-8	DWT	4.362793	2.678922
	IDWT	3.447764	2.046081
	MSER	3.325277e-30	3.353076e-30

TABLE V

COMPARISON OF SPATIO-TEMPORAL 3D-DWT AND TEMPORO-SPATIAL 3D-DWT FOR LEVEL 3

Video Name	*Time & MSER*	*Spatio-temporal*	*Temporo-spatial*
Video-1	DWT	0.198695	0.108257
	IDWT	0.143771	0.090866
	MSER	1.401704e-30	1.500251e-30
Video-2	DWT	3.177423	1.805498
	IDWT	2.377956	1.382495
	MSER	1.800211e-30	1.889084e-30
Video-3	DWT	3.120123	1.754683

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Video Name	*Time & MSER*	*Spatio-temporal*	*Temporo-spatial*
	IDWT	2.347888	1.351186
	MSER	8.757494e-31	8.702828e-31
Video-4	DWT	NA	NA
	IDWT	NA	NA
	MSER	NA	NA
Video-5	DWT	7.917204	4.243129
	IDWT	6.021513	3.250916
	MSER	9.372880e-30	9.316827e-30
Video-6	DWT	NA	NA
	IDWT	NA	NA
	MSER	NA	NA
Video-7	DWT	2.340794	1.359153
	IDWT	1.763724	1.031772
	MSER	2.781412e-30	2.767324e-30
Video-8	DWT	4.894616	2.615989
	IDWT	3.618737	2.087642
	MSER	5.854649e-30	5.822715e-30

NA : Not Applicable

V.RESULTS

Results for various videos listed in table-II are discussed here. In the figures shown below i.e., from figure-6 to figure-11, 'a' represents the spatio-temporal encoded frame, 'b' represents the spatio-temporal decoded frame, 'c' represents the temporo-spatial encoded frame and 'd' represents the temporo-spatial decoded frame. Corresponding frame numbers are represented at the figure caption and the levels are represented in the sub-headings. The graphs taken between the spatio-temporal and temporo-spatial are shown in figure 12 to figure-14. Figure-12 represents the graph between the MSER and 3D-DWt level applied, figure-13 represents the time taken for encoding and 3D-DWT level applied and figure-14 represents the time taken for decoding and 3D-DWT level applied.

1) Results of video-1: (level-2)

Fig. 6(a) (frame # 10)

Fig. 6(b) (frame # 34)


Fig. 6(c) (frame # 10)


Fig. 6(d) (frame # 34)

2) Results of video-2: (level-3):


Fig. 7(a) (frame # 38)


Fig. 7(b) (frame # 33)


Fig. 7(c) (frame # 38)


Fig. 7(d) (frame # 33)

3) Results of video-3: (level-2)


Fig. 8(a) (frame # 28)


Fig. 8(b) (frame # 60)


Fig. 8(c) (frame # 28)


Fig. 8(d) (frame # 60)

4) Results of video-4: (level-1)

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Fig. 9(a) (frame # 151) Fig. 9(b) (frame # 68)


Fig. 9(c) (frame # 151) Fig. 9(d) (frame # 68)

5) Results of video-7: (level-4)


Fig. 10(a) (frame # 12) Fig. 10(b) (frame # 85)


Fig. 10(c) (frame # 12) Fig. 10(d) (frame # 85)

6) Results of video-8 : (level-5)


Fig. 11(a) (frame # 59) Fig. 11(b) (frame # 223)


Fig. 11(c) (frame # 59) Fig. 11(d) (frame # 223)

Graphs:

Values taken in graph are of video-2, which is listed in table-I.

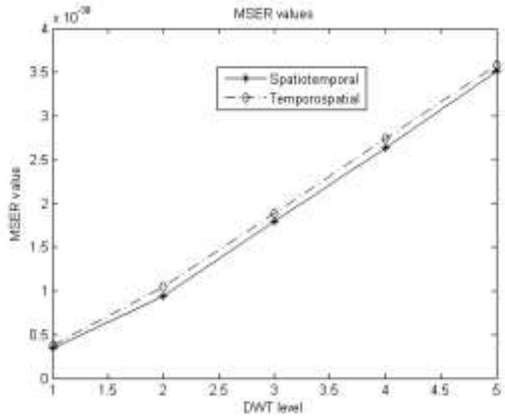

Fig. 12: Graph between MSER and 3D-DWT level

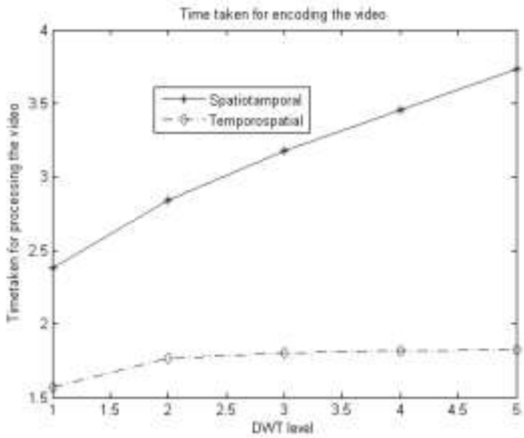

Fig. 13: Graph between MSER and 3D-DWT level

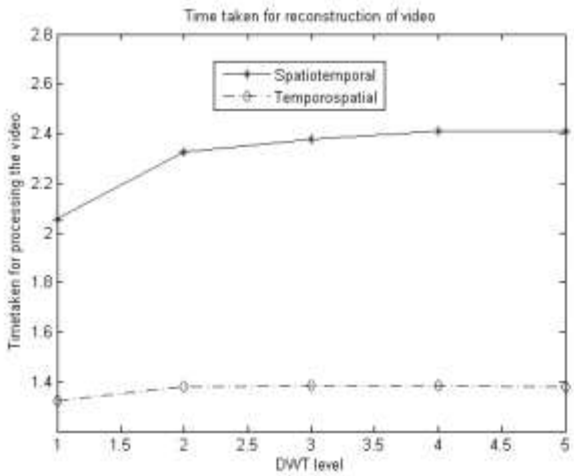

Fig. 14: Graph between MSER and 3D-DWT level

VI.CONCLUSION

In this paper, the comparison of spatio-temporal 3D-DWT MRA with the temporo-spatial 3D-DWT MRA on the basis of time taken for encoding and decoding the video is presented. 3D MRA is very much suitable for the application of compression techniques such as 3D-SPIHT, 3D-EZW etc. Hence, one can say that one can achieve better compression if we use these 3D MRA generating mechanisms which are discussed in this paper with video compression techniques.

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