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VLSI Architectures for 3D Discrete Wavelet Transform and Applications of Wavelet Transform– A Comprehensive Study

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Abstract- ***Wavelets have become an integral part of modern day computing. They find tremendous applications in almost all of the domains of signals and systems, image processing, computing, medical data analysis, etc. The aim of this paper is to throw light on wavelets through a scrutinizing study of the rich collection of literature on VLSI architectures. The possible application domains are also discussed.***

Key Words – *Wavelets, 3D DWT.*

1. INTRODUCTION

Wavelets contain rich underlying mathematical concepts that can be attributed to its mass-acceptance and creation of new avenues in research. They are used widely as tool in a broad spectrum of science and engineering. They are an inevitable part of image and signal processing, approximation theory, analysis of time series, geophysics and many diverse fields. Wavelets were first deployed in seismology for rendering a dimension of time for analysis of seismic signals where Fourier analysis doesn't serve the purpose. The analysis of stationary data can easily be accomplished via Fourier analysis where the statistical parameters remain unchanged over time. However, the technique is not applicable for transient data events wherein the prediction based on the past data is not possible. This shortcoming was overcome with the advent of wavelets and thus has been applied in a large spectrum of disciplines. Currently, domains like quantum mechanics, computer science, signal processing, mathematics, image processing, have deep rooted applications of wavelet transforms. Real time applications include, computer graphics and animation, finger print matching, heart abnormality detection, image compression and smoothing, weather prediction, breast cancer diagnosis, protein and DNA analysis, Electro-cardiogram (ECG), Electro-encephalograph (EEG), Electro-occulograph (EOG) analysis; blood-pressure, pulse and heart rate analysis, Galvanic Skin Response (GSR), face, speech and gait recognition; internet traffic, finance, etc.Wavelet transforms can be divided into three broad categories:Fast Wavelet Transform (FWT), Continuous Wavelet Transform (CWT) and Discreet Wavelet Transform (DWT)

2. LITERATURE SURVEY

Owing to its decorrelation feature, the DWT has gained mass-acceptance, right from the time of its invention [1] in the transformation stages for images, compression, video, etc. [2]. This is evident from the literature dedicated to their research. The rich source of available literature either focuses on novel approaches to build effective DWT schemes, or to optimize the existing ones in terms of memory, control, speed, throughput and other related factors. This chapter aims to give a brief survey of the attempts made so far in implementing the DWT architectures and the suitable measures undertaken for their optimization.

Zerves, et al, [3] proposed that there can be 3 architectures for a 2D DWT viz. line-based, level-by-level and block based. The line based architecture is typically used for the implementation of the 2D DWT using recursion. The image that needs transformation is stored in the form of a 2D array. The convolution on the row is performed, once the elements in it are accessible. This row-wise convolution can divide the image into 2 parts.

Kaur, et al, [4] compared the efficiencies of both the DWT and the DCT based methods for image compression. It was found that DWT avoided artifacts related to blocking and rendered higher compression ratios. It also provided better localization in both the frequency and spatial domains. Also the time complexity of DWT was lesser in comparison to DCT.

Darji, et al, [5] designed and proposed a high throughput, memory efficient design for lifting based 3D DWT. The implementation was carried out on a Virtex IV family based FPGA. To reduce the complexity and the internal memory requirement, a unique frame management scheme has been introduced. The efficiency of the proposed architecture was compared against existing ones. It was seen that the proposed architecture gave better performance results but at an increased area.

Altogether, the 3D DWT processor could compute 44 full HD frames per second.

Jen-Shiun Chiang, et al, [6] proposed a VLSI architecture using DWT for 2D lifting based 5/3 filter. The main focus was to reduce the area of silicon and to achieve full utilization of hardware. Also, it was found that the memory requirement was least in comparison to other architectures and the data flow was regular. This architecture was found to be appropriate for VLSI based implementation and could be used effectively to operate MPEG4 and JPEG2000 applications.

Mansouri, et al, [7] devised VLSI architecture for real time video and image processing using 2D DWT. The system ensured low control complexity, least power consumption and lower space and time complexities. The system was designed specifically for JPEG2000 encoder system for applications like digital cinema. The correctness of the architecture was tested using VHDL and routed in Cyclone II FPGA at 290 MHz and Stratix III at 350 MHz. Totally 48 frames corresponding to 4096 X 2160 per second was the coding achieved by the FPGA implementation at 24 BPP. It was also applicable in MPEG-4 methods.

Thomas, et al, [8] proposed the compression technique using SPIHT on real time space images from NASA. Several variants of DWTs were tested and the folded DWT design was used exclusively for the study. Also, the storage elements necessary for the wavelet coefficients are discussed. In order to parallelize the operations, a feasible, yet effective alteration to the original SPIHT algorithm is employed. The SPIHT architecture used is a Fixed –Order SPIHT designed especially for adaptive hardware. The system was designed using Annaplis Microsystems WildStar with Xilinx Virtex-E.

Mohamed, et al, [9] compared the efficiency of both the Haar and the Daubechies wavelet transforms using FPGA. The result obtained via simulation is compared by the Bit Error Rate (BER) against the reconstructed output signal and the audio input signal. It was found the Daubechies wavelet outperformed Haar in case of audio applications. The results confirm the efficiency of the FPGA as rapid and reliable method to realize the inverse wavelet transform and the wavelet transform.

Yong Liu, et al, [10] reported the design of 2D biorthogonal DWT using Residue Number System (RNS) arithmetic. The results from the synthesis confirmed the fitting of the entire system on a 1,000,000 gate FPGA. To reduce distortion at the boundaries of the image, a symmetric extension scheme is used. By using the hardware sharing method, the reduction in hardware complexity and the improvement in utilization are achieved.

Chung-Jr Lian, et al, [11] proposed a reconfigurable lifting based 1D DWT. In order to achieve optimum utilization of hardware and to reduce the hardware costs, the implementation makes use of the folded architecture. Using the hardwired multiplier, the multiplication operation is realized along with coefficients depicted in CSD format, which is an effective and compact DWT core for implementing the hardware of JPEG 2000.

Chao-Tsung Huang, et al, [12] have proposed a 3 generic architectures based on RAM which provides enhanced efficiency along with feasible solutions for 1-level and multiple level line based 2D DWT. The advantages begotten from the implementation were minimal internal memory size, less complex control circuits and real time applications. The advanced lifting absed and the convolution based 1D DWT modules can be amalgamated with the proposed module. The performance characteristics of the architecture is shown by the adoption of JPEG 2000 default (9, 7) along with (5, 3) filters.

Shih-Chung, et al, [13] proposed a Neural Network based approach for finding a wavelet kernel that was optimal and could be used in image processing. Linear convolution NN was used to obtain a wavelet to maximize compression efficiency and to minimize error when applied to images. It was found that the Daubechies wavelet could produce high compression ratios for digital images. Also, the Haar wavelet produced gave optimum results in low-noise smooth areas and on the sharp edges. The wavelet with the highest optimal coefficients of the low pass filter returned best preservation outcomes.

Basant K., et al, [14] made an attempt to optimize the memory requirements by overlapping the group of frames by using scheduled computing at various levels. It was observed that the memory complexity of 3D DWT was reduced drastically. The proposed design was compared with the existing ones and it was noticed that the design used reduced frame buffer, low on-chip memory and less ACT. For 60 fps frame rate and 176 X 144 frame sizes, the proposed design gave 12.3% less ACT and consumed 7.96 times lesser memory than [15]. When compared with the design given in [16], the proposed design consumes 4.28 times lesser memory and gives double ACT values for constant frame rates and constant size. Owing to the least memory consumption, the proposed design had the advantage of least dynamic power when compared to the other designs. Also, the design was capable of handling 3D DWT for infinite groups of frames.

Anirban, et al, [17] proposed a lifting based 3D DWT design coupled with the novel idea of the running transforms. The proposed design has been executed successfully on Xilinx Virtex-IV. The contributions of their work include memory referencing, least storage requirement, lower power consumption and latency and enhanced throughput. This was evident when compared to the existing methodologies. The design can provide new avenues for video processing at real time with single adder at the critical path with the mapped processors working at the rate of 321 MHz. The proposed design was found to be feasible for future 3D wavelet based computing machines.

Zeinab Taghavi, et al, [18] proposed a new method for the implementation of an n-D wavelet transform which is basically based on the lifting scheme. It was found that the method was much faster than the standard method. The efficiency in terms of memory and speed is guaranteed since it makes efficient usage of both the slow and the fast memory of the processor. The comparison results presented is in good agreement of the fact that the proposed algorithm outperformed the rest for implementing n-D wavelets, especially for n = 3).

B. Das, et al, [19] presented a simple yet effective design of 3D DWT based on regular data-flow patterns using 4 tap Daubechies architecture. It is this regularity that adds to the benefits like low power consumption and increased speed. The design architecture in case of 2D DWT in spatial domain bestowed better results than the existing ones (hardware optimization and memory usage). Though the design is capable to be used in real time scenarios, the compression effectiveness is compromised for video sequence data.

Jizheng Xu, et al, [20] proposed transform architecture using lifting based 3D wavelets that gives minimal delay and least memory consumption. The notable contribution of the paper was the elimination of the boundary effects inherent in the 3D wavelet video coders. The boundary effects mainly occur across group of pictures (GOP) boundaries. The design improved the visual quality of the decoded video. Thus the proposed work enabled 3D wavelet cased method more acceptable than MC- DCT based approach.

Qionghai Dai, et al, [21] presented a new VLSI design for multidimensional DWT. The comparisons with respect to the 2D cases revealed the advantages of the proposed scheme over the rest. The technique is based on systolic array. Here, the m-D input data is divided into 2^m independent data streams. These are then pipelined simultaneously into a multi filter chip. Then 2 samples are obtained with varying DWT subbands. For N1 X N2 X … X Nm image, the proposed design decomposed in around N1N2…Nm/(2m-1)ccs. Hence, the hardware cost was relatively lower than the other existing approaches. The other advantages obtained were regular data flow, simpler hardware and lower control complexities.

Michael Weeks, et al, [22] proposed 2 designs to configure the 3D DWT viz. 3DW-I and the 3DW-II. These were analyzed thoroughly via simulation to establish their correctness. The 3D DW-I allowed the equal distribution of the load of processing on the 3 filter sets. This architecture was another advent of the 3D DWT. In case of 3D DW-II, the design contained a single high/low filter pairs to accommodate the processing of the outputs. The disadvantages of each design were overcome by the other.

Karthekeyan, et al, [23] presented a design for lossy compression based on the lifting scheme of CDF97 filters and Daubechies (9, 7) filters. This comes at the advantages like faster computing speeds, lower control complexity, lower power consumption and saving of embedded memories.

The architecture is specifically designed for low power and high performance JPEG2000 encoder for digital cinema use cases. The drawbacks of the study being, the scheme was not extended to multi-level DWT and the delay characteristics were not optimized.

3. APPLICATION DOMAINS

Discreet Wavelet Transform find tremendous applications in the field of preconditioning for data compression, acoustics, sub-band coding, astronomy, nuclear engineering, image and signal processing, Magnetic Resonance Imaging (MRI), Electro-encephalography (EEG) in neuroscience, music, discrimination of speech, prediction of earthquakes via seismic waveform analysis, data compression, fractals, pure mathematics, optics, turbulence, radar, computer vision, etc. In a broader sense, wavelets are also being utilized in quality control, outlier analysis, geophysics, biology and biological computing, astrophysics, imaging technology, traffic modeling in networking, aural signal analysis for medical science, video-signal coding, weather forecasting, etc. The following sections elaborate some these well-known applications in detail.

3.1 Data compression

DWT approximation finds tremendous applications in data compression in case the signal is sampled while the CWT is for the analysis of the signals. The former is used in various domains of computer science and engineering disciplines. Wavelet transform renders the transformation of the data which can then be encoded, thereby ensuring actual compression. For instance, biorthogonal wavelets are used in case of JPEG 2000. Based on the thresholding of the coefficients of wavelets, the smoothing and denoising of data is accomplished. This is often termed as wavelet shrinkage.

3.2 Estimation of the soil temperature profile

The depth profile of soil temperature analysis is explained with respect to Haar Wavelet Transform as follows:

The equation of heat diffusion in soil is given by

$$\frac{\partial u}{\partial t} = K \frac{\partial^2 u}{\partial z^2} \qquad (1)$$

where K refers to the thermal diffusivity and K = $\frac{c_1}{c_v}$; c_v represents the volumetric heat capacity while c_1 is indicative of the thermal conductivity. The mean of heat stored is given by u. The value of K signifies the rate at which the temperature of soil changes.

The assumption necessary to solve the diffusion equation with Haar wavelet transform is

$$\frac{\partial u}{\partial t} = a_0^t e^{(-z\sqrt{1/2K})^{p^{\frac{-1}{2}}}} H(t) \qquad (2)$$

The application of the integration matrix to (2) yields,

$$u(x,t) = a^t P\,H(t) \qquad (3)$$

This can be further be reduced to the form,

$$u(x,t) = a_0 e^{(-z\frac{1}{\sqrt{K}})} P\,H(t) \qquad (4)$$

Hence, the Haar wavelet can be used for to solve the soil heat problem.

3.3 Fingerprint analysis and verification

Graphical patterns of valleys and ridges on the surface of finger tips are called fingerprints which uniquely characterize an individual. One kind of widely-used features is called *minutiae*, which is usually defined as the ridge ending and the ridge bifurcation. Minutiae- based fingerprint representation techniques are widely in use. The barriers faced in extraction of minutiae are the variations in pressure, large displacements, noise, etc. The verification of fingerprint can be used as a reliable and most secure means of biometric identification. Its applications range in forensic sciences too. High end fingerprint analyzers basically use infrared scanners to detect the blood's hemoglobin content to assess the vein patterns of the finger. These patterns in turn establish unique identity of a person. Wavelets are used to store the fingerprint data in a compact and a secure manner. This scenario could be ironically be compared against the US FBI agency, who once stored large sets of fingerprint data in paper formats in tight security buildings at Washington. The area required was not less than the size of a football field. Comparison of the fingerprints with these stored datasets was highly time-consuming and unreliable procedure. This created an urge to generate methods for storage of such data electronically. Consider a fingerprint to be a tiny image. The image is then divided into square-inch sizes- for example, 256 X 256 pixels. Now, this is associated with a grey tone scale that specifies 0 for complete white portion and 256 for black portions. In this fashion, sequence of number pairs is obtained which contains the associated data of grey-tones and the numbering of the pixels. This can be stored rather in a very compact format and transferred at a rapid pace. The technique uses 10 Mb of space for storage. The FBI agency has over 30 million fingerprint datasets (for each of the ten fingers). Per day, 30,000 new datasets are being added to their databases. Owing to such a large set of data, the compression of these is very vital. Hence, wavelet transforms are used in this regard.

3.4 Music

As proposed by Victor Wickerhauser, the wavelet packets can be used for the synthesis of sound. In order to approximate the sound produced by a musical instrument, the notes of music can be decomposed into packets of wavelet coefficients. Reconstruction of these notes requires the coefficients to be reloaded in a wavelet packet generation system and then the resulting output an then be played. The provision to alter the variations in sound can be provided.

3.5 Breast cancer detection

The detection of breast cancer in medical images is possible due to the advent of mammography. Mammography is basically a diagnostic based breast imaging method that deploys X-rays. It is widely accepted tool to detect, assess and characterize breast cancer. Due to its low cost and high performance, it is adopted on a large scale.

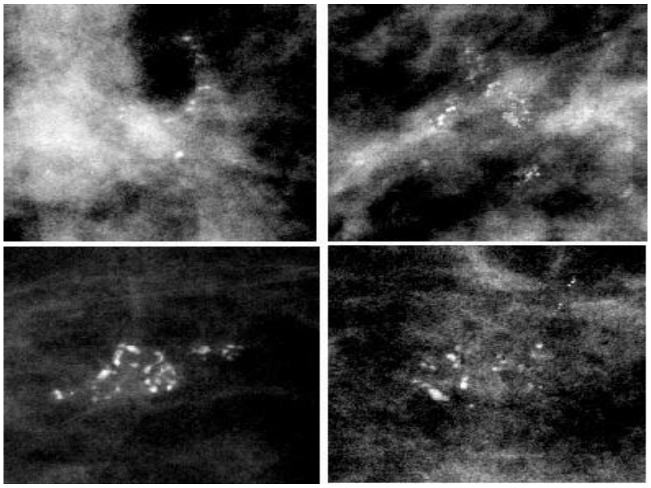

Fig. 1 Malignant (left) and benign (right) microcalcification clusters

3.6 Face recognition

Face recognition basically deals with acquiring a static or dynamic (video) face image and comparing it for recognition process. The face image is subjected to extraction of features. Face recognition suffers from major shortcomings like variations in illumination, pose, gender, expressions, age, occlusions, etc. Popular face databases are available which serve as benchmarks to test the robustness of any face recognition algorithms. This technique finds tremendous applications in Mugshot, surveillance, etc.

3.7 Denoising of noisy data

Most of the fields of science and engineering face a common scenario wherein the parsing of the crude data signals is rather difficult due to the inherent noise and artefacts in the data. Wavelets can be used in this regard to denoise the signals with via a method known as thresolding or wavelet shrinkage, proposed by David Donoho from Standford University. When a dataset or a signal is decomposed using wavelets, the tools like filters, etc used for the purpose generate wavelet coefficients. This corresponds to the detail in the signals. These details can be rejected in case they are very small, without affecting or losing the valuable information in the rest of the signals. Thresholding is then used to set all the coefficients to zero for the values that are below the determined threshold. Inverse wavelet transforms make use of these wavelets to rebuild the data. Thus the method is well suited for denoising of noisy signals.

3.8 Computer graphics

One of the core domains of computer graphics is the manipulation and development of the surfaces and curves. Wavelet transform finds wide usage in this field when it comes to variation modeling, compact geometry representation, interactive editing, etc. Such areas are prevalent in animations as well.

3.9 Analysis of Electro-encephalograph data

Human brain consists of millions of neurons connected into a complex manner. These neurons fire electrons and this ejection is a function of human activites, both voluntary and involuntary. The ejected neurons contain rich source of data pertaining to the cognitive states of a person. This can be assessed by using EEG which comes with a varying number of electrodes. Commercial available low cost EEGs have made it possible to run Brain-Computer Interface based applications at a lower affordable price. Currently many BCI applications are been developed due to such less complex and portable EEG devices [25].

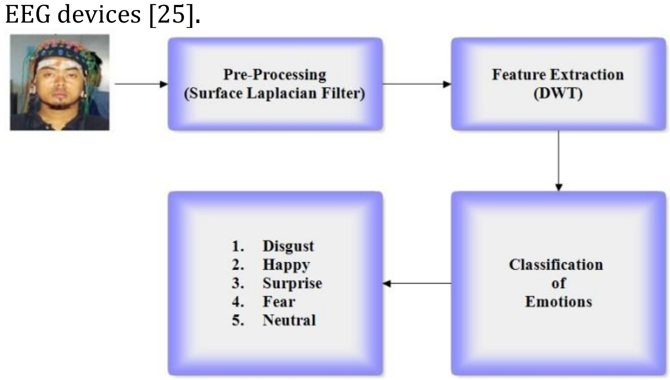

Fig. 2 Classification of emotional states

This analysis on the other hand, is very complex, since the EEG waveforms vary significantly for every activity. Moreover, the inherent noise due to muscle movements, respiration, interference from external devices, make the analysis more complex. The usage of DWT in this regard plays a vital role. Murugappan et al.,[24] used DWT to classify the emotions of the subjects. Here DWT was used to extract useful information from the spectrum of EEG waveforms- alpha, beta, gamma, theta, delta, etc. This can be well understood from Fig. 2.

3.10 Electro-Cardiograph (ECG)

ECG provides the means to record and assess the electrical activity associated with the heart. The frequency domain analysis of ECG signals requires the usage of Fast Fourier Transform (FFT) but the major shortcoming prevalent here is that the method is incapable of determining the exact frequency domain locations in time. Both the STFT and FFT fail to effectively meet the needs of

ECG analysis. Wavelet transforms serve the purpose. Currently, Db 6 is being deployed for ECG signal analysis.

4. CONCLUSIONS

As a summary, this paper draws sharp contrast between the theoretical background of the wavelets and the associated application domains. It can be noted that wavelets have successfully enhanced each of the domain that they are into. Proper analysis and application of wavelets is prejudicial to extract maximum outcomes.

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REFERENCES

[1] Olivier Rioul and Martin Vetterli, *"Wavelets and Signal Processing",* IEEE Trans. on Signal Processing, Vol. 8, Issue 4, pp. 14 - 38 October 1991.

[2] D. S. Taubman, *"High performance scalable image compression with EBCOT",* IEEE Transaction Image Processing, Vol. 9, No. 7, pp. 1158–1170, July 2000

[3] Evaluation of Design Alternatives for the 2-D-Discrete Wavelet Transform. Nikos D. Zervas, Giorgos P. Anagnostopoulos, Vassilis Spiliotopoulos, Yiannis Andreopoulos, and Costas E. Goutis. DECEMBER 2001, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, Vols. 11, NO. 12, pp. 1246-1262.

[4] Kaur, Amanjot, and Jaspreet Kaur. "comparison of DCT and DWT of Image Compression Techniques." International Journal of Engineering Research and Development 1.4 (2012): 49-52.

[5] Darji, Anand, et al. "Hardware Efficient VLSI Architecture for 3-D Discrete Wavelet Transform." VLSI Design and 2014 13th International Conference on Embedded Systems, 2014 27th International Conference on. IEEE, 2014.

[6] Jen-Shiun Chiang, and Chih-Hsien Hsia, "An Efficient VLSI Architecture for 2-D DWT using Lifting Scheme," IEEE International Conference on Systems and Signals, pp. 528-531, April 2005, Taipei, Taiwan.

[7] Mansouri, A., A. Ahaitouf, and F. Abdi. "An efficient VLSI architecture and FPGA implementation of high-speed and low power 2-D DWT for (9, 7) wavelet filter." IJCSNS International Journal of Computer Science and Network Security9.3 (2009): 50-60.

[8] Fry, Thomas W., and Scott A. Hauck. "SPIHT image compression on FPGAs."Circuits and Systems for Video Technology, IEEE Transactions on 15.9 (2005): 1138-1147.s

[9] Mahmoud, Mohamed I., et al. "Comparison between haar and daubechies wavelet transformations on FPGA technology." World Academy of Science, Engineering and Technology 26 (2007): 68-72.

[10] Liu, Yong, and E. M. Lai. "Design and implementation of an RNS-based 2-D DWT processor." Consumer Electronics, IEEE Transactions on 50.1 (2004): 376-385.

[11] Lian, Chung-Jr, et al. "Lifting based discrete wavelet transform architecture for JPEG2000." Circuits and Systems, 2001. ISCAS 2001. The 2001 IEEE International Symposium on. Vol. 2. IEEE, 2001.

[12] Huang, Chao-Tsung, Po-Chih Tseng, and Liang-Gee Chen. "Generic RAM-based architectures for two-dimensional discrete wavelet transform with line-based method." Circuits and Systems for Video Technology, IEEE Transactions on 15.7 (2005): 910-920.

[13] Shih-Chung B.Lo, Huai Li, Yue Wang, Lisa Kinnard, Matthew T. Freedman, "A multiple Circular Path Convolution Neural Networks system for detection of Mammographic Masses," IEEE Transactions on Medical Imaging , Vol. 21, No. 2, February 2002.

[14] Mohanty, Basant K., and Pramod Kumar Meher. "Memory-efficient architecture for 3-D DWT using overlapped grouping of frames." Signal Processing, IEEE Transactions on 59.11 (2011): 5605-5616.

[15] Q. Dai, X. Chen, and C. Lin, "A novel VLSI architecture for multidimensional discrete wavelet transform," IEEE Trans. Circuits Syst., Video Technol., vol. 14, no. 8, pp. 1105–1110, Aug. 2004.

[16] B. K. Mohanty and P. K. Meher, "Parallel and pipeline architecture for high-throughput computation of multilevel 3-D DWT," IEEE Trans.Circuits Syst., Video Technol., vol. 20, no. 9, pp. 1200–1209, Sep. 2010.

[17] Das, Anirban, Anindya Hazra, and Swapna Banerjee. "An efficient architecture for 3-D discrete wavelet

transform." Circuits and Systems for Video Technology, IEEE Transactions on 20.2 (2010): 286-296.

[18] Taghavi, Zeinab, and Shohreh Kasaei. "A memory efficient algorithm for multi-dimensional wavelet transform based on lifting." Acoustics, Speech, and Signal Processing, 2003. Proceedings.(ICASSP'03). 2003 IEEE International Conference on. Vol. 6. IEEE, 2003.

[19] Das, B., and S. Banerjee. "Data-folded architecture for running 3-D DWT using 4-tap Daubechies filters." IEE Proceedings-Circuits, Devices and Systems152.1 (2005): 17-24.

[20] Xu, Jizheng, et al. "Memory-constrained 3D wavelet transform for video coding without boundary effects." Circuits and Systems for Video Technology, IEEE Transactions on 12.9 (2002): 812-818.

[21] Dai, Qionghai, Xinjian Chen, and Chuang Lin. "A novel VLSI architecture for multidimensional discrete wavelet transform." Circuits and Systems for Video Technology, IEEE Transactions on 14.8 (2004): 1105-1110.

[22] Weeks, Michael, and Magdy A. Bayoumi. "Three-dimensional discrete wavelet transform architectures." Signal Processing, IEEE Transactions on 50.8 (2002): 2050-2063.

[23] Karthikeyan, A., P. Saranya, and N. Jayashree. "An Efficient VLSI Architecture for 3D DWT Using Lifting Scheme." International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2 (2013).

[24] Murugappan, Murugappan, Nagarajan Ramachandran, and Yaacob Sazali. "Classification of human emotion from EEG using discrete wavelet transform."Journal of Biomedical Science and Engineering 3.04 (2010): 390.

[25] Geeta Navalyal, Rahul Gavas, "A dynamic attention assessment and enhancement tool using computer graphics", Human-centric Computing and Information Sciences 2014 4:11, Springer. doi:10.1186/s13673-014-0011-0

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