VLSI IMPLEMENTATION OF ERROR TOLERANCE ANALYSIS FOR PIPELINE BASED DWT IN JPEG 2000 ENCODER

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ABSTRACT
The JPEG 2000 image compression standard is designed for a broad range of data compression applications. The Discrete Wavelet Transformation (DWT) is central to the signal analysis and is important in JPEG 2000 and is quite susceptible to computer-induced errors. These errors get spread to many output transform coefficients if the DWT is implemented by using lifting scheme. This paper proposes an efficient Error Tolerance Scheme (ETS) to detect errors occurring in DWT. A pipeline-based DWT structure is also developed in this paper to speed up the error detection process. Some standard images are used as test samples to verify the feasibility of the proposed ETS design. Experimental results and comparisons show that the proposed ETS achieves better performance in error detection time and error tolerance capability.

KEYWORDS: *JPEG 2000, DWT, error detection, error tolerance.*

I. INTRODUCTION

JPEG 2000, a still-image compression standard is being designed to address many applications, e.g., internet, printing, and medical imagery [1] & [2]. Besides, it achieves better compression performance over the JPEG, JPEG 2000 also provides rich features. For example, it allows efficient lossy and lossless compressions within a single unified coding framework, provides superior image quality at low bit rates, supports additional features such as region of interest coding, and has a more flexible file format, avoiding excessive computational and memory complexity. The DWT is central to the JPEG 2000 image compression standard which includes lifting configurations for implementing the forward and inverse transforms. The main properties of DWT are the space-frequency localization and inherent multiresolution structure. In other words, wavelets allow efficient representation of a signal with a small number of nonzero coefficients. Also, wavelets take advantage of data correlation in space and frequency. DWT is implemented with computer hardware ultimately, the processing operations are susceptible to transient failures, and primarily single-event upsets, alternately termed as soft errors. These factors will increase the influences as VLSI feature sizes shrink [3].

Error tolerance is a new design and test paradigm, which takes into consideration whether erroneous outputs of defective circuits still produce acceptable results [5] & [6]. Error tolerance classifies a system as being acceptable/ unacceptable by estimating the performance degradation due to errors, rather than relying solely on the conventional perfect/imperfect classification. Error tolerance analyzes the system level effects of errors, and accepts circuits if the performance degradation can meet the application-specific or range of acceptability.

This paper proposes an ETS design that targeted for detecting errors of the DWT subsystem in JPEG 2000, as DWT is one of the most important subsystems in terms of both computation and memory requirements. The remainder of this paper is organized as follows: Section II reviews the basic principles and key features of DWT by lifting scheme. In section III presents the proposed ETS structure, pipeline-based DWT design, error model definition, error detection, and tolerance strategy. Section IV shows the experimental results and comparisons for performance evaluation and discussion. Finally, Section V provides the final conclusions.

II. BACKGROUND

The DWT is usually computed through convolution and sub-sampling with a couple of filters to produce an approximation signal L (low pass filter result) and a detail signal H (high pass filter result). The multi-resolution decomposition is obtained by iterating the convolution and sub-sampling of these two filters over the approximation components. For 2-D signals, there exist separable wavelets for which the computation can be decomposed into horizontal processing (on the rows) followed by vertical processing (on the columns), using the same 1-D filters. Figure 1 shows a one level decomposition. Subsequent levels are obtained by iterating on the low pass signal LL [3] & [4].

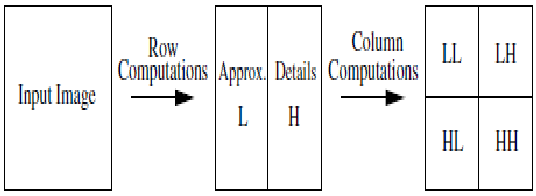


Figure 1. A 1-Level 2-D seperable wavelet decomposition

The general block diagram of the lifting technique is illustrated in Fig. 2, which consists of four steps:
1. Split step: The original samples are separated into two disjoint sets, named even part and odd part.
2. Predict step: The even samples are multiplied by the time domain equivalent of s(z) are added to the odd samples.
3. Update step: The updated odd samples are multiplied by the time domain equivalent of t(z) are added to the even samples.
4. Scaling step: The even and odd samples are multiplied by k^{-1} and k, respectively.

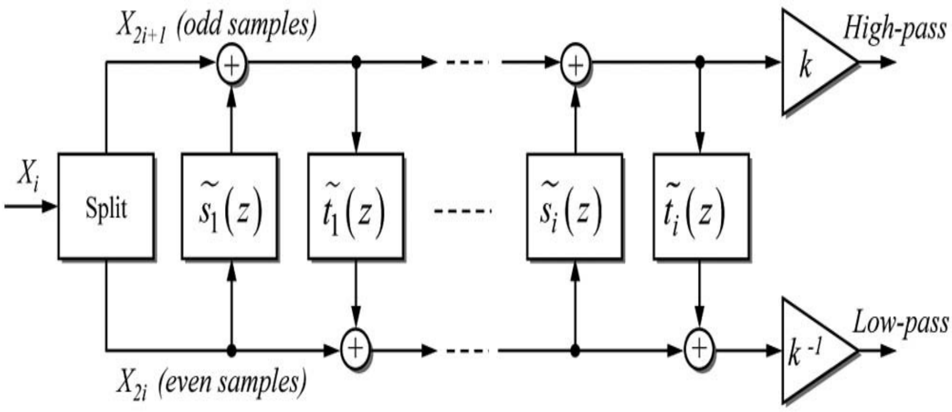


Figure.2. Block diagram of the lifting scheme.

III. PROPOSED ERROR TOLERANCE SCHEME

The Proposed ETS design which consists of an Input Parity Procedure (IPP), an Output Parity Procedure (OPP) and a parity analyzer. The main objective of the ETS is to compare the differences between C_{in} and C_{out} values to find the errors that occurred in the DWT. Then the parity analyzer will further analyze, whether the errors can be tolerated or not. Each row pixels of an n× n image will be divided into even and odd number of data samples input for DWT operation. Thus, the size of input-data vector X shown in Fig.3 is 1× n. A is n × n matrix of wavelet transform via lifting. Additionally a

1×n tolerance weighting matrix W has to be developed to establish the IPP and OPP structures for error detection.[1]

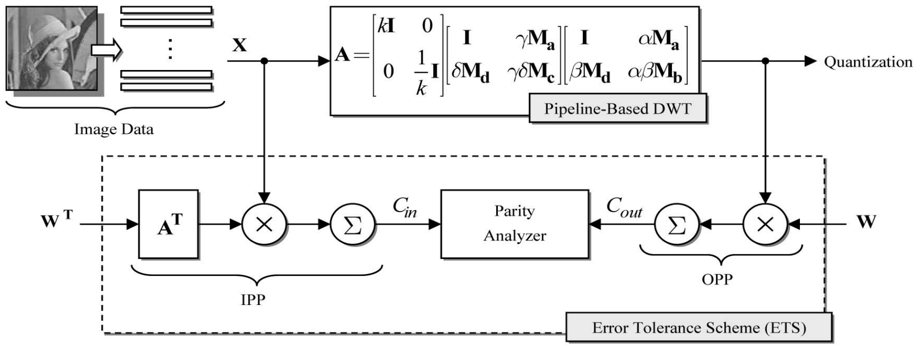


Figure.3. Block diagram of the ETS design

3.1 Modeling Errors

The proposed ETS design mainly focuses on the effects of computer-induced errors, which will be modeled through transfer matrices related to the lifting sections. Forward 2D DWT, the numerical errors are caused by an underlying computer-induced error which will propagate their corrupting influence to the output. The error mechanisms can be defined by two types such as Intensive Error Model (IEM) and Distributed Error Model (DEM), as shown in figure.4. If the numerical errors influence the pixels in contiguous rows of an image, then the error model is called IEM. On the other hand, the DEM is presented if many single row pixels of an image will be influenced by the numerical errors. According to the error models, the proposed ETS design will be demonstrated as an effective method to explore the error impact in the DWT and further analyze the tolerance of errors for JPEG 2000 encoder applications [11].

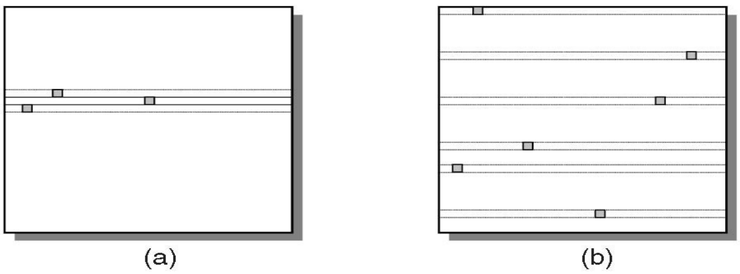


Figure. 4. Error models. (a) IEM. (b) DEM

3.2 Tolerance Weighting

In order to achieve the error tolerance of human visual system and to increase the flexibility of the proposed ETS design, a tolerance weighting matrix, W has to be developed. The weighting factors of W are very important for error tolerance analysis, since the most significant data are generally centralized in the central parts of an image. The error influence in the central parts is more serious than that in the boundaries of an image. Thus, a weighting matrix has to be built for supporting evaluation of error influence when the proposed ETS is active. Fig 5 shows an image divided into some blocks to set the different parity weighting factors. Generally, good parity weighting factors should have gain factors whose ranges span three to four orders of pixel magnitude. Based on the parity weighting factor, we built a 1×n tolerance weighting matrix for error detection and error tolerance evaluation purpose [1].

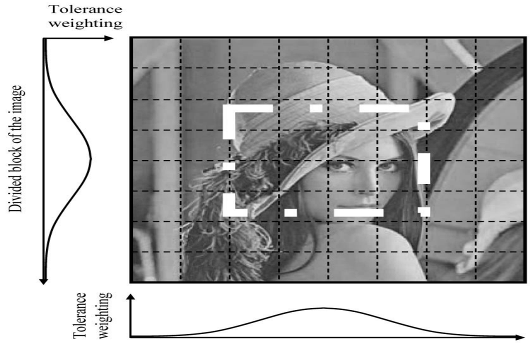


Figure.5. Schematic representations of parity weighting of an image

3.3 Pipeline-Based DWT Design

Based on the conventional structure for one level 9/7 DWT via lifting. Initially input data samples are split into odd and even subsequences.

For an nxn image, the input-data vector is represented by,

$X= [x_0\ x_1\ x_2\ x_3.......x_{n-2}\ x_{n-1}]$ (1)

$s0= [x0\ x2.......xn-2] = [s_0^0\ s_1^0\ .....s^0_{(n/2)-1}]$ (2)

$d0=[x1\ x3.......xn-1]= [d_0^0\ d_1^0.....d^0_{(n/2)-1}]$ (3)

Where s^l_i and d^l_i represent the i^{th} even and odd samples in the l^{th} stage of lifting step.

Split step

The input sequences x_i are split into even and odd parts, s^0_i and d^0_i

$d_i^0 = x_{2i+1}$ (4)

$s_i^0= x_{2i}$ (5)

Lifting step

The two splitting sequences (s^0_i and d^0_i) are performed by two lifting steps

Step1

$d_i^1= d_i^0 +\alpha \times(s_i^0+s^0_{i+1}),$ (6)

$s_i^1= s_i^0 +2\beta \times(d_i^1)$ (7)

Step2

$d_i^2= d_i^1 +\gamma\times(s_i^1+s^1_{i+1})$ (8)

$s_i^2= s_i^1 +2\delta \times(d_i^2)$ (9)

Scaling step

Through the normalization factors $k^{-1}$and k, the low-pass and high-pass wavelet coefficients s_i and d_i can be obtained.

$d_i= k \times d_i^2$ (10)

$s_i= k^{-1} \times s_i^2$ (11)

The final output of the pipeline based DWT is expressed in the following matrix form

$$\begin{bmatrix}\mathbf{d}\\ \mathbf{s}\end{bmatrix} = \begin{bmatrix}k\mathbf{I} & 0\\ 0 & k^{-1}\mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{d}^2\\ \mathbf{s}^2\end{bmatrix}$$
$$= \begin{bmatrix}k\mathbf{I} & 0\\ 0 & k^{-1}\mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{I} & \gamma\mathbf{M_a}\\ \delta\mathbf{M_d} & \gamma\delta\mathbf{M_c}\end{bmatrix}\begin{bmatrix}\mathbf{d}^1\\ \mathbf{s}^1\end{bmatrix}$$
$$= \begin{bmatrix}k\mathbf{I} & 0\\ 0 & k^{-1}\mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{I} & \gamma\mathbf{M_a}\\ \delta\mathbf{M_d} & \gamma\delta\mathbf{M_c}\end{bmatrix}\begin{bmatrix}\mathbf{I} & \alpha\mathbf{M_a}\\ \beta\mathbf{M_d} & \alpha\beta\mathbf{M_b}\end{bmatrix}\begin{bmatrix}\mathbf{d}^0\\ \mathbf{s}^0\end{bmatrix} \quad (12)$$

where M_a, M_b, M_c, and M_d are the nxn matrices and the parameters α, β, γ, δ and k represent floating point arithmetic for a 9/7 wavelet transform via lifting[12].

The direct mapping of 1-Dimensional lifting based architecture for the 9/7 filter is shown in the figure 6.

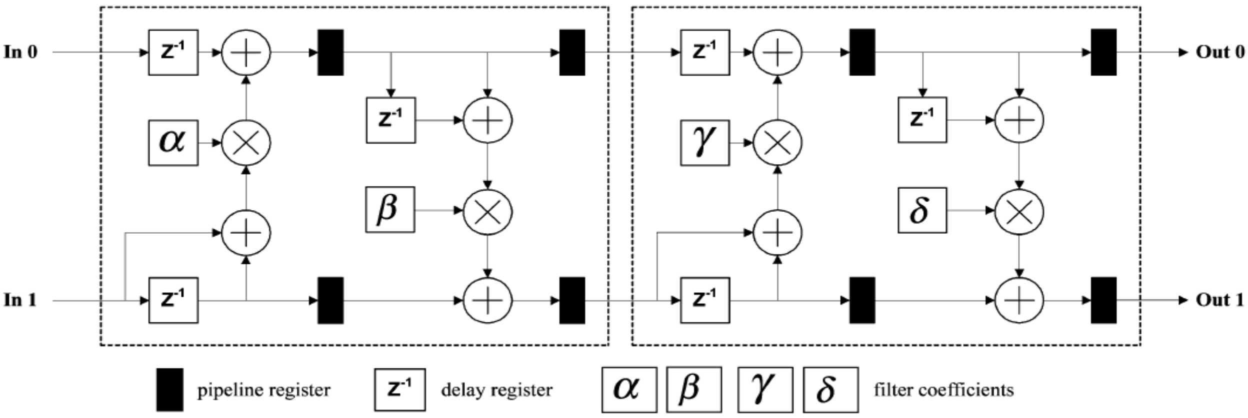


Figure.6. Direct mapping of 1-D lifting-based architecture for the 9/7 filter

3.4 Parity Analyzer

The parity analyzer plays the role of a comparator to check a syndrome (the difference between C_{in} and C_{out}) and determine whether a syndrome is tolerant with a chosen threshold or not. The thresholds of IEM and DEM are defined as TH_{IEM} and TH_{DEM}, respectively, to detect the Intensive and Distributed errors in an image as shown in equation (13).[9]

$$\sum_{i=j}^{k-j+1} |C_{in-i} - C_{out-i}| \geq TH_{IEM}$$

$$\sum_{i=1}^{n} |C_{in-i} - C_{out-i}| \geq TH_{DEM} \quad (13)$$

The human visual system is more sensitive about the brightness variations than the changes in chrominance. Thus, the brightness variation detection method which plays an important role for error detection in an image is adopted here to redefine the thresholds of error detection. For the computational efficiency consideration, the criterion of brightness variation is determined by using the histogram- based method, which usually shows sensitivity to the image changes within a similar brightness condition. The histogram difference is given by equation (14).

$$D_{HIS} = \sum |H_j - H_i| \quad (14)$$

where H_i and H_j signify the histograms in the i^{th} and j^{th} rows of an image. By setting threshold of the histogram difference D_{HIS}, the image holding brightness variations can be detected [1].

In order to accurately evaluate the quality impact of an image by brightness variations, the BVRs are normalized as fractional variations. The Brightness Variations for Intensive Error Model and Distributed Error Model is given by the equation(15) and (16) respectively.

$$BVR_{IEM} = \frac{\sum_{i=j}^{k-j+1} [C_{in-i} - C_{out-i}]}{\sum_{i=j}^{k-j+1} [C_{in-i}]} \times 100\% \qquad (15)$$

$$BVR_{DEM} = \frac{\sum_{i=1}^{n} [C_{in-i} - C_{out-i}]}{\sum_{i=1}^{n} [C_{in-i}]} \times 100\% \qquad (16)$$

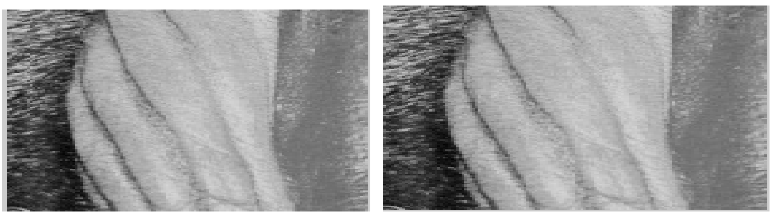
3.5 Acceptable Error Rate

The objective evaluation of a specific image presented here depends on the relation between BVR and acceptable error rate (AER). Error rate (ER) is the percentage of vectors for which values at a set of outputs deviate from error free response, during normal operation. AER is a percentage of acceptable errors for all injection errors; AER represents the capability of error tolerance with injection errors in an image [15].

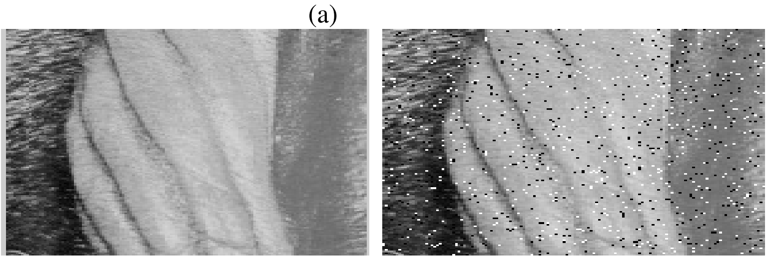
$$AER = \frac{\text{Acceptable Error Rate}}{\text{Total Injection Errors}} \times 100\% \qquad (17)$$

IV. EXPERIMENT RESULTS

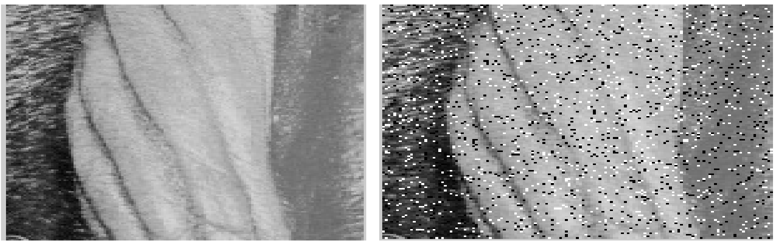
The 9/7 lifting DWT of the JPEG 2000 image compression standard is used as a Circuit Under Test (CUT) to demonstrate the good performance in error detection time and error tolerance capability of the proposed ETS design. Consider the lifting DWT operating with error injection values modeled by a Gaussian noise source. The error detection performance is strongly dependent on the noise variation and the selected detection threshold. C_{in} - C_{out}, from the parity analyzer of the proposed ETS is on the order of 10^{-10} with round off errors. Thus, the necessary thresholds have to be chosen well above this level for error detection. To examine the effectiveness of the proposed ETS design in different experimental conditions, six benchmark sequences (Lena, Peppers, Baboon, Barbara, Gold hill, and Cameraman) are selected in the experiments. The comparisons between the proposed ETS design and the work are presented in this section to demonstrate that the proposed ETS design has good performance in error detection time. Additionally, quality observation and objective analysis are discussed to evaluate the capability of error tolerance.



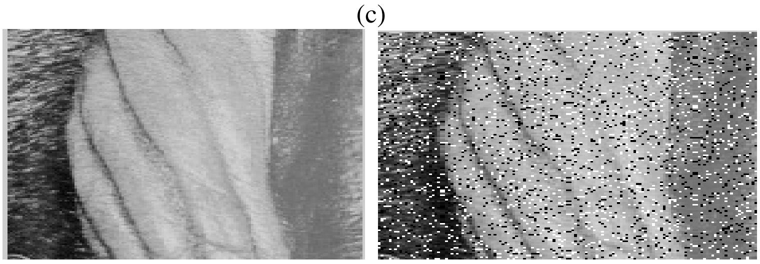
(a)



(b)



(c)



(d)

Figure.7. Quality observation for the benchmark image “Baboon**.**”
(a) Error free. (b) BVR_{DEM} = 6.2%. (c) BVR_{DEM}=12.1%. (d)BVR_{DEM}=18.7%.

4.1 VLSI Simulation output for pipeline based DWT

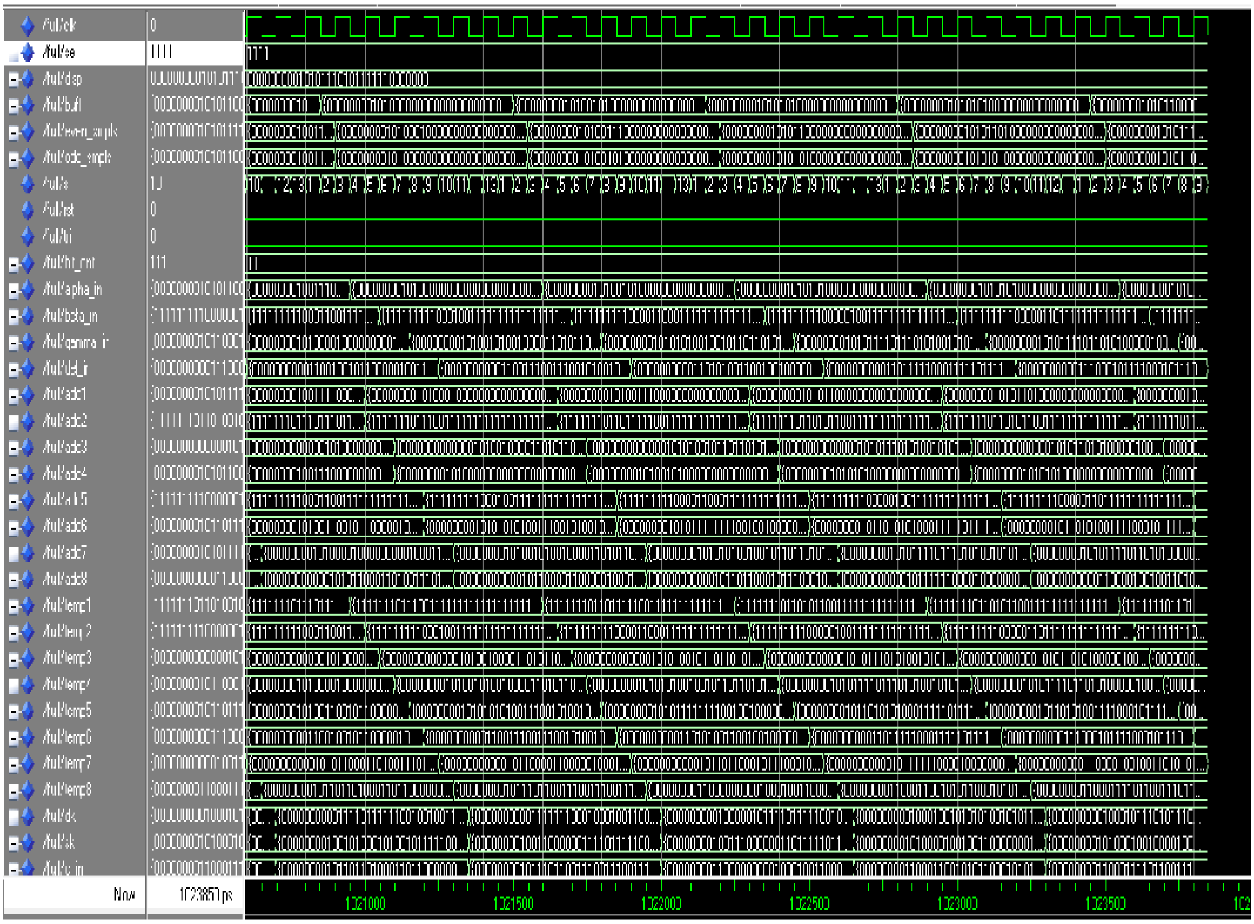


Figure.8. Simulation output for pipeline based DWT

4.2 Table 1: Acceptable Error Rate (AER) for Test Images

Threshold Test images	BVR $_{IEM}$($TH_{IEM}=10^{-4}$)				BVR $_{IEM}$($TH_{DEM}=10^{-7}$)			
	2%	**4%**	**6%**	**8%**	**2%**	**4%**	**6%**	**8%**
	AER%				**AER%**			
Lena	6.5	12.1	18.9	24.9	4.9	10.9	17.2	22.3
Peppers	5.1	9.8	14.9	19.9	4.2	9.1	14.1	18.7
Baboon	7.0	13.1	19.8	27.1	6.2	12.1	18.7	25.1
Cameraman	5.1	10.7	16.2	22.1	2.1	5.2	8.6	11.8

4.3 Comparisons

The proposed ETS design shown in Fig. 4 can be implemented by using a comparator and some multipliers, adders, buffers, and registers. Based on the circuit design shown in [8], the number of logic gates of the proposed ETS design is about 6,972. However, about 180 k logic gates are needed for a VLSI architecture design of JPEG 2000 encoder [3]. Thus, the area overhead of the proposed ETS design is only about 3.9 percent, which is a reasonable design for circuit testing. The comparisons between the proposed method and previous work [9] are shown in Table 2, which clearly indicates that the proposed ETS design has good performance in computational complexity (error detection time) and error tolerance capability with little area overhead.

Table2: Comparison Results

	DWT Design	**Computational complexity**	**Area overhead**	**Tolerance analysis**
Proposed work	Pipelined based structure	$O(n^2)$	3.9%	Error Tolerance
Existing work	Conventional structure	$O(n^3)$	-	Fault Tolerance

V. CONCLUSION

An effectively ETS design for lifting DWT error detection and error tolerance evaluation in JPEG 2000 encoder is presented in this paper. The paper first developed a pipeline based DWT structure to support the proposed ETS design for speeding up the error detection time. Then, an IPP, an OPP, and a parity analyzer based on the weighting sum technique are built of the proposed ETS design to detect the errors. The error detection performance depends on the detection thresholds, which are determined by the brightness variations. Experimental results show that the proposed ETS with pipeline-based DWT design can significantly improve the error detection time compared with the previous work with conventional DWT structure. Additionally, according the quality observation and objective evaluation for the test images, the proposed ETS design also demonstrates the good performance in error tolerance capability.

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