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ASIC Implementation of Finger Print Recognition Using Overlap-Add and Integer Wavelet Transform Methods

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Abstract—The field of fraud identification is reaching a very high proportion in the society, thus leading to an increase in the need for fingerprint-based identification. This paper presents ASIC implementation of fingerprint recognition based on Overlap-add method and Integer Wavelet Transforms. In overlap-add method, the present output overlaps the next output and in the integer to integer wavelet, low component at 2^{nd} level decomposition is taken as approximate integer value. The implementation presents an analysis for speed, area and power dissipation between the two algorithms and other methods.

Index Terms—Biometrics, Fingerprint Identification, Overlap-add Method, Integer Wavelet Transform, Application Specific Integrated Circuits.

I. INTRODUCTION

Biometrics is the science and technology of analyzing and measure biological data. Biometric methods of identification are referred to traditional methods mainly for two reasons:

- At the time of verification, the physical presence of the identifying person is required.
- Identification based on biometrics avoids the need to remember the password or carrying a token.

Fingerprints, palm-print, Iris etc., are some types of biometrics based method to identify individual person to verify their identity. Fingerprint recognition is the most reliable method for person identification and plays an important role in criminal investigation, terrorist identification and national security issues. The impression of the fingerprint contains friction ridges. They are, unique in nature, detailed, difficult to alter and durable for the life span of human being. Fingerprint recognition refers to the automated method of verifying a match between human fingerprints.

The analysis and study of fingerprints for matching compares the several print pattern features. This fingerprint contains patterns like ridges and minutia points, which are unique features of patterns. A fingerprint is represented by location, types, and some attributes like angle of inclination of minutiae etc., are shown in Fig 1. One hundred years of study on fingerprints ensures the uniqueness of minutiae based representation for a very large population in the world. To establish the identity, 50 to 150 minutiae's are enough but in automated systems 10 matching minutiae are assumed to be sufficient.

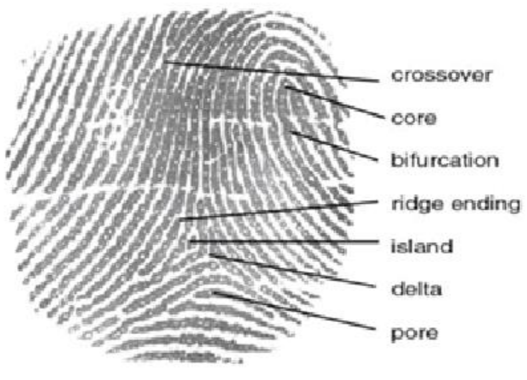

Fig.1. Fingerprint Features

II. RELATED WORK

One of the previous methods for fingerprint identification is Henry Classification System [1], which creates the primary groupings based on fingerprint pattern types from the logical categorization of ten-print fingerprint records. Over the years, Principal Component Analysis (PCA) was an efficient approach in the pattern recognition [2]. This approach effectively extracts the global features from the aligned fingerprint images. PCA transforms a number of correlated variables into uncorrelated variables known as principal components.

Anil K. Jain [3] in his paper has proposed filter bank based algorithm for fingerprint recognition. Gabor filters are used to consider the global and local details of fingerprint. Anil K. Jain, et. al,[4] have proposed a method on the combination of different fingerprint matching algorithms to develop the performance of a Finger Print Recognition (FPR) system. In this paper they have combined the scores values from logistic transform, which are generated from three dissimilar fingerprint matching algorithms. Arun Ross, Anil K Jain and Salil Prabhakar [5] have proposed fingerprint matching using minutiae and texture features. F. G. Hashad, et. al. [7] have introduced Mel Frequency Cepstral Coefficients (MFCCs) for Fingerprint Recognition. Manisha Redhuand and Dr.Balkishnan [9] has proposed new method in FPR system. They used score values obtained from matching method and image enhancement is done by using histogram technique and FFT. S. Gayathri and Dr. V.Sridhar [12] have shown the ASIC implementation of fingerprint recognition process. The efficiency of the fingerprint recognition system depends on the minutiae obtained from the unprocessed image.

The objective of this paper is to design a high speed, low area based fingerprint recognition system, which can process every fingerprint image of the user. The finger print identification has been implemented by using two algorithms: they are Fast Convolution and Integer Wavelet Transforms. The fast-convolution method uses overlap add method than overlap save method, because overlap save method saves previous stage outputs, thus requiring huge memory. In the overlap add method the previous stage is not saved and hence memory requirement will be less. The integer wavelet is a 2nd level transformation technique to transform the low order coefficient in the time-frequency domain. With an On-chip architecture being developed for a high speed and low area FPR system, the designed system is verified as an IP for Functionality and Performance. The rest of the paper is organized with Section II describing the overlap-add method and IWT algorithm used. Section III presents simulation results and performance evaluation of the systems. Section V gives the conclusion for the paper.

III. METHODOLOGY

The flow diagram shown in the Fig 2 explains general process of fingerprint recognition. The thresholding/binarization and skeletonisation are the pre-processing steps and feature extractions are common to both the algorithms. Features of fingers are extracted using fast convolution and IWT method after which, bit wise matching is done using hamming distance.

A. *Thresholding/Binarisation*

In fingerprint image the foreground have high grey value and the background regions exhibit a low grey-scale value. Hence in thresholding is performed based on threshold values. First, the image is divided into number of blocks and for each block grey-scale mean is calculated. If the grey value (Gi) of a particular pixel is less than the mean of that block (Bi), then zero is assigned otherwise one is assigned. The outcome of this process is shown in Fig 3, is a binary image having two levels of information.

$$I(x; y) = 0; \text{ if } Gi < Bi; = 1; \text{ otherwise}; \quad (1)$$

B. *Skeletonisation*

Skeletonisation of binary images is done by a process called thinning that reduces all lines to a single pixel thickness. Thinning algorithm retains the connectivity of ridge structures while forming a skeletonised finger image. To eliminate a pixel the following conditions must be considered:

- The pixel will not be reasoned as an endpoint.
- The elimination of pixel does not break connections of the skeleton.
- The elimination does not cause excessive erosion of the region.

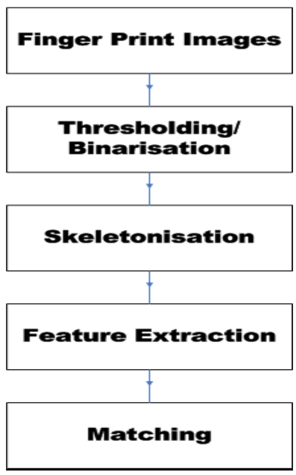

Fig.2. Flow Diagram for Fingerprint Recognition

Fig.3. Binarized Image

In the Fig 4 is the skeletonized image used in the subsequent extraction of minutiae. After Skeletonisation the features like ridges, delta points are extracted using Overlap-add and IWT method, as explained in the following sections.

C. Feature Extraction

i. Overlap add method

The overlap-add method is a type of convolution for fixed coefficients and it is computationally efficient but requires more memory. This method can be applied to frequency domain and time domain using DFT and IDFT techniques. In basic convolution technique, after the multiplication the output values are added. The final output will be very long sequence, to computation of these long sequence is very difficult. In overlap add method the output from the rear end of the former block is overlapped with the front end of the present block. The process of overlapping and addition of the convoluted signal is carried out. Hence the name overlap-add method. In this work overlap add method is used for feature extraction. The Fig 5 shows overlap-add method procedure, the input signal is f and it is split into small signal. Then it is convoluted with the kernel g. Each convoluted blocks are overlapped and then added. Finally we get the convoluted sequence. The length of this sequence obtained is less than the basic convolution method.

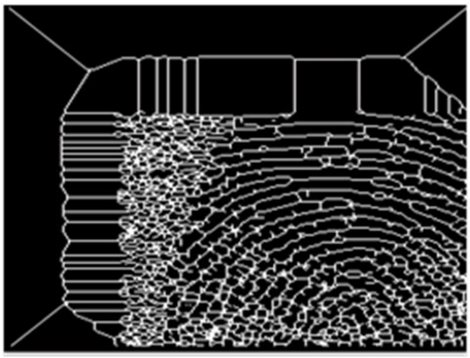

Fig.4. Skeletonized Image

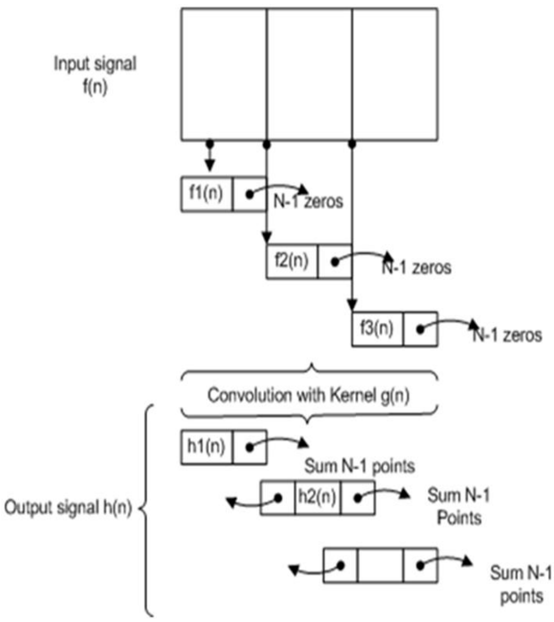

Fig.5. Overlap add method

First the input signal f is split into smaller disjoint tiles f1; f2; :::; fm. Therefore f(n) = f1(n) + f2(n) + :. For the computation of convolution the selected signal f_i and the large kernel g is considered. That is,

$$h(n) = f(n)*g(n); f(n) = f1(n)+f2(n)+f3(n)+::::f (n)*g(n) = (f1(n)+f2(n)+f3(n)+::::)*g(n)h(n) \quad (2)$$

Let us consider a input block of size L points and the size of DFT and IDFT will be N = L+M-1. To compute N point DFT concatenate each block with M-1 zeros. Therefore the data block will be,

$$x1(n) = x(0); x(1); ; x(L-1); 0; 0; :; 0x2(n) = x(L); x(L+ 1); ; x(2L-1); 0; 0; :; 0x3(n) \quad (3)$$

& So on.

Therefore 2N point DFT is,

$$Y_m(k) = H(k)X_m(k) \qquad k = 0; 1; :::;N-1 \quad (4)$$

The IDFT having data block of length N are free from aliasing, the sequence of DFT & IDFT is increases to N points by concatenating zeros. Each block is terminated by M-1 zeros, the last M-1 points from each output block is overlapped and added to the 1^{st} M-1 points of the immediate block.

That is,

$$Y (n) = y1(0); y1(1); :y1(L-1); y1(L) + y2(0); y1(L + 1) + y2(1); :::; y1(N-1) + y2(M-1); y2(M); \quad (5)$$

Overlap add is a linear convolution method between the infinitely long input signal x(k) & the finite impulse response K_i as shown in Fig 5. The following points are explained by the Fig 5. Fig 5 overlap add method in frequency domain

- Add the impulse response K_i with N zeros in window g & transform to frequency domain with $K_l(m)$ with l=0,1,. . . , 2N-1, follows for every iteration m=0,1,2,. . .
- Choose N samples from signal x(m) and add these by N zeros in segment to produce a block
- Transform to frequency domain which results in the frequency bins $X_l(m)$ with l=0, 1, .2N-1.
- Convolute $X_l(m)$ & $W_l(m)$ for l=0, ...2N-1.
- Transform back convoluted values to time domain using IDFT $e_i(m)$ with i=0, 1,....2N-1.
- Perform desegmentation to generate the output signal with k=mN+I calculated as The algorithm of overlap add method is,
- Break the input signal f (n) into non-overlapping blocks $f_m(n)$ of length L.
- Pad zero for g(n) to be of length N = L + M - 1.
- Take N-DFT of g(n) to give G(k), k = 0,1,. . .N-1.
- For each block m:

- Zero pad fm(n) to be of length N = L + M -1.
- Take N-DFT of $f_m(n)$ to give $F_m(k)$, k = 0,1,....N -1.
- Multiply: $H_m(k) = F_m(k) * G(k)$, k = 0,1,....N -1.
- Take N-IDFT of $H_m(k)$ to give $H_m(n)$, n = 0,1,....N -1.

- Form h(n) by overlapping the last M -1 samples of $h_m(n)$ with the rest M -1 samples of $h_m+1(n)$.
- The adding overlapped samples of $h_m(n)$ and $h_m+1(n)$.
- The 5 DFT overlap add method is shown in Fig 6.

Fig 6 Overlap Add Method with 5 DFTs in frequency domain.

ii. Integer wavelet transform

The second algorithm is used to extract the finger image feature is Integer Wavelet Transform (IWT). The disadvantage of DWT is that it contains real numbers as wavelet coefficients. So efficient lossless coding is not possible using linear transforms. The lifting scheme (LS) is an efficient implementation of the DWT and also perfect reconstruction is ensured. This creates new transformation, like integer wavelet transform (IWT). IWT is a basic modification of linear transforms, in which output is rounded to the nearest integer. It is also of interest for hardware implementations, where the use of floating point is still a costly operation.

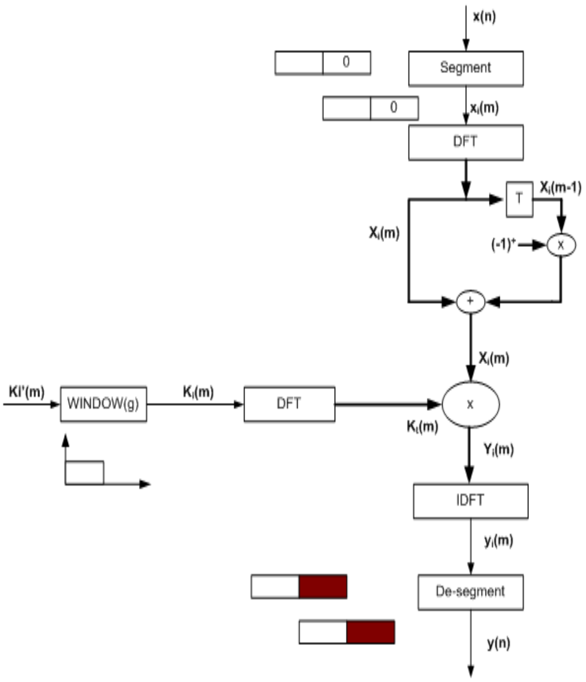

Fig.6. Overlap add method

The convolution based DWT needs a large number of arithmetic computations and a large memory for storage. The IWT requires fewer computations compared to the convolution based DWT. In IWT the computational complexity is reduced to almost a half as compared to convolution approach.

The main advantages are as follows:

- It consents to a faster implementation.
- It permits fully in place calculation, in other words, no auxiliary memory is needed and the original signal (image) can be replaced with its wavelet transform.
- By reversing the operations, the inverse wavelet transform is created.

There are several frameworks are explained, in that most popular are S+P, Lifting scheme and overlapping rounding transform (ORT) frameworks. The S-transform is the most basic framework for ITI transform. The below section briefly describes the S-transform for the basics of ITI and also other three frameworks which are generally used.

S-Transform: The Sequential (S) transform is uncomplicated and ubiquitous ITI transform. The S transform is the approximated (linear) Haar transform of ITI and is allied with UMD filter bank as shown in Fig 7. The forward and inverse transform is calculated by the analysis and synthesis side of the filter bank respectively as shown in Fig 7. The mathematical analysis of the S-transform is given by,

$$Y_0\,[n]=[1/2(x[2n]+x[2n+1])] \qquad (6)$$

and

$$Y_1\,[n]=[1/2(x[2n]-x[2n+1])] \qquad (7)$$

Where the forward transform divides the input signal x[n] into low $y_0[n]$ and high $y_1[n]$ pass components. The above forward transform are considered for infinite length and for finite length the symmetric and periodic extension can be considered. The S-transform shows two key remarks, first any two coefficient values are calculated from their sum and difference. Second, the sum and difference of any two coefficients have same parity (which omits the fractional part without losing information).

S+P transform: This transform is known as sequential plus prediction, it is a direct extension of S-transform. The framework of S+P transform is shown in Fig 7, mathematically it can be expressed as

$$Y_0\,[n]=[1/2(x[2n]+x[2n+1])] \qquad (8)$$

and

$$Y_1\,[n]=[v\_0[n]-[t[n]+1/2]] \qquad (9)$$

$$y_0\,[n]=[1/2(x[2n]-x[2n+1])] \qquad (10)$$

and

L_0, L_1 and K are integers satisfying $L_0 \leq L_1$ and $K \leq 1$.

The forward transform divides the input coefficients x[n] into low-pass and high-pass coefficients as $y_0[n]$ and $y_1[n]$ respectively.

From the above equations, it is found that the S+P transform is generated by adding an extra step to S-transform; that is the high-pass component of S-transform is adjusted with an extra prediction operation. The predictor component α_i and β_i is shown in table 1.

Table 1. Predictor Co-efficient

Predictor	α_{-1}	α_0	α_1	β_{-1}
A	1/4	1/4	0	0
B	3/8	2/8	0	0
C	8/16	4/16	1/16	6/16

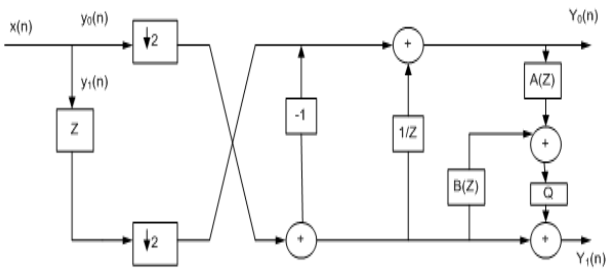

Fig.7. S+P transform with UMD filter bank

Lifting framework: The most popular framework of ITI transform is based on the lifting scheme. The lifting framework is a polyphase comprehension of UMD filter banks, which adopts ladder networks for filtering. The 1-D two channel UMD filter bank contains 2 steps, they are lifting and scaling steps. In lifting step, the filters A_k is constituted and in scaling step the amplifiers of gain s_k as shown in Fig 8.

The ladder network of lifting scheme has to sustain their invariability even for quantization error (rounding error by finite precision arithmetic). The construction of lifting scheme based ITI transform follows initially to constrict the lifting scheme, eliminate the scaling function having a non-integer gain factor, and then transforms each lifting step to the rounding operation Q at the output of its corresponding filter as shown in Fig 8.

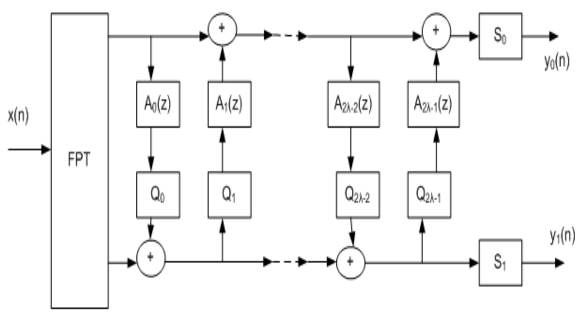

Fig.8. Lifting framework with UMD filter bank

Overlapping Rounding Transform: Overlapping Rounding Transform (ORT) framework is a polyphase apprehension of UMD filter bank. The Fig 9 shows the forward transform of 1-D two channel UMD filter bank. The cascade of two input two outputs ITI networks is performed from polyphase filtering.

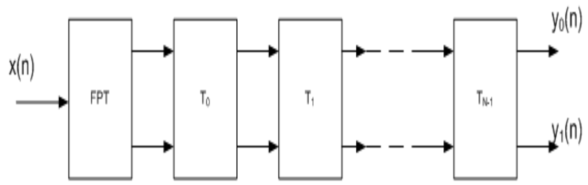

Fig.9. Overlapping Rounding Transform

Finger features are extracted by using the lifting scheme based ITI transform.

D. Minutiae Reduction

Minutiae are the trivial details of fingerprint. An unavoidable source of error in fingerprint recognition is false minutiae. These are inevitable because of distortion such as scars, sweat, etc. Existence of false minutiae forces the matching process to fail. It is possible to handle excessive numbers of them; therefore after the feature extraction phase, the minutiae list is analyzed to eliminate false minutiae. Our approach is to eliminate minutiae features using distance criteria, e.g., minutiae which are too close to each other are discarded. For a particular minutiae point within the D8 distance (also called as chessboard distance), only one minutia point is considered. Any other minutiae point existing within of 3 are all eliminated.

E. Matching using Hamming Distance

The Hamming distance between two strings of equal length is calculated by creating a sequence of logical Boolean values indicating matches and mismatches between their position in the two inputs, and then summing the sequence.

$$I(x,y)=I(x_i,y_i) \text{ xor } I(x_j,y_j) \quad (11)$$

IV. Result

The inputs which are described in the modules are functionally verified using ModelSim. After the successful completion of simulation, the design is synthesized using Cadence tool.

The input image is in matrix form. Image enhancement is done for the images to improve the quality \& mean is calculated. If the grey value of a particular pixel is less than the mean of that block then zero is assigned, otherwise one is allotted. The outcome is an binary image containing two logical levels of information. Skeletonisation is done using thinning process to reduce all lines to single pixel values. The skeletonized image is used for feature extraction, which is done using overlap add method of fast convolution and IWT. Then the minutiae reduction is done to remove false minutiae. Finally matching of the test fingerprint with the reference images is done.

A. *Fast Convolution Method*

Fig 10 shows the top module of Overlap-add Method, if the test image is matched with the reference image. It shows the end point branch points and matching score.

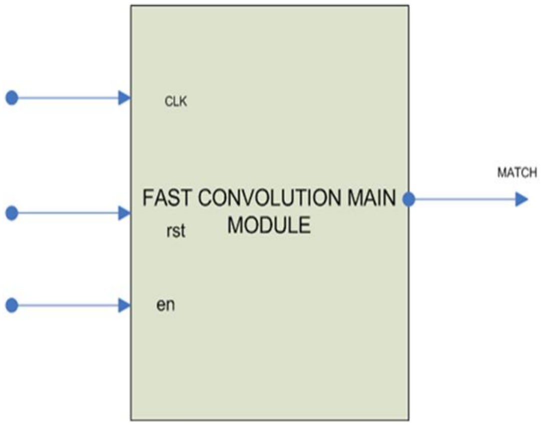

Fig.10. Finger Print Top Module for overlap add method

Table 2 describes the signal details of the top module.

Table 2. Signal Description of Top Level Module.

Signal	I/O	Description
CLK	Input	Synchronous clock signal of finger print top module
rst	Input	Reset signal
en	Input	Enable signal
MATCH	Output	The final authentication match signal

Table 2 describes the signal details of the top module. The simulation results for the finger print top module are given in Fig 11 and Fig 12. In this module the two finger images are obtained from the text file. All these data are of eight bit in nature. The module operates for the positive edge of clk and rst=0. Initially when the clk signal is at the positive edge and rst=1, no data evaluation process is taking place as shown in Fig 11 and Fig 12. Fig 11 shows the unmatched condition if the test image does not match with the reference image. It shows that fingerprint is not identified.

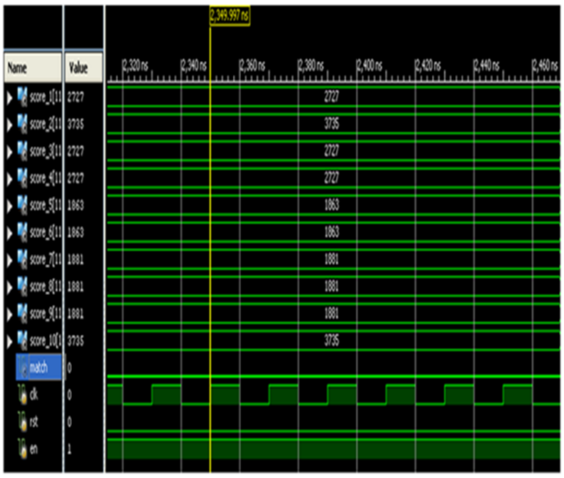

Fig.11. Simulation Results for Unmatched Condition

In Fig 12 the matched condition is shown, when both the test and reference finger images are same, the match signal is 1.

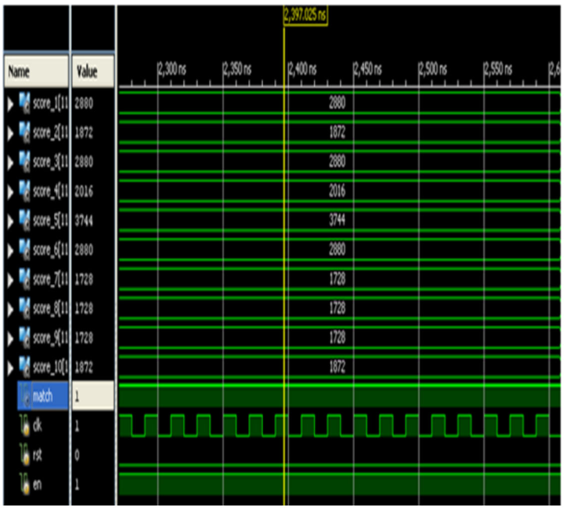

Fig.12. Simulation Results for Matched Condition

The resultant cell layout is shown in Fig 13. The Table 3 and Table 4 describe the memory usage and power utilization before routing. The total area of 9100.560 μm^2, the total power 444030.394nW and total cells of 1496 in that sequential gate of 1211 and the logic gate count of 743.

Table 3. Area Utilization Summary of overlap add Method

Instance	No. of Cells	Cell Area
Sequential	1211	8036.582 μm^2
Inverter	212	212.420 μm^2
Logic	743	851.558 μm^2
Total Area	1496	9100.560 μm^2

Table 4. Power Utilization Summary of overlap add Method

Leakage Power	291.522 nW
Dynamic Power	443738.872 nW
Total power	444030.394 nW

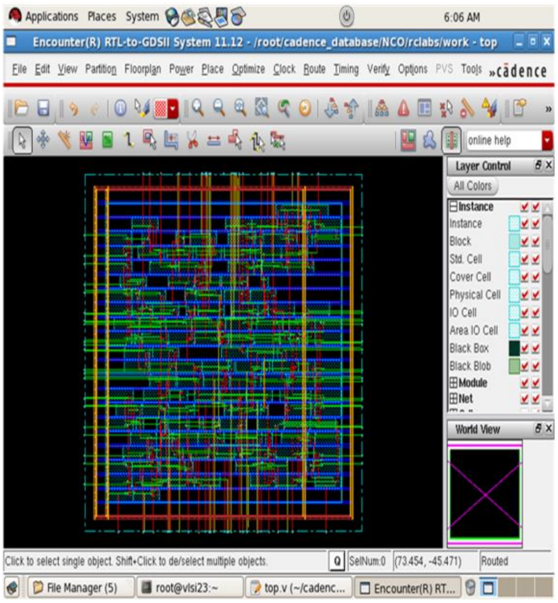

Fig 13. Final routed Cell layout of the overlap add Method

B. Integer Wavelet Transform

The top module of Integer Wavelet Transform as shown in Fig 14. Table 5 describes the signal details of this top module.

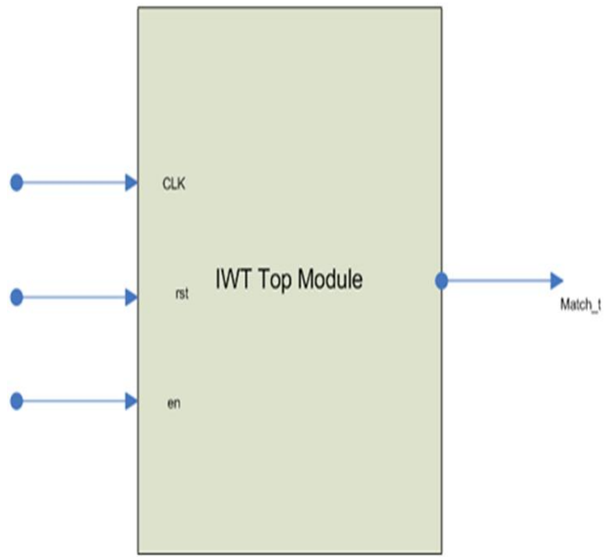

Fig.14. Finger Print Top Module for Integer Wavelet method

Table 5. Signal Description of IWT Top Level Module

Signal	I/O	Description
CLK	Input	Synchronous clock signal of finger print top module
rst	Input	Reset signal
en	Input	Enable signal
Match_t	Output	The final authentication match signal

The simulation results for the finger print top module are shown in Fig 15 and Fig 16. The module operates for positive edge of clk and rst signal i.e, when rst is 1 the data is considered else the module resets to zero. Fig 15 shows the unmatched condition if the test image does not match with the reference image. It shows that fingerprint is not identified with match as zero.

In Fig 16 the matched condition is shown, when both the test and reference finger images are same, the match signal goes to 1.

The cell layout as shown in Fig 17 and Table 6 and Table 7 shows the area and power dissipation of IWT based finger print module. The total area of 53271 µm^2 having 8752, sequential cells of 912 has 23701.104 µm^2 of area, the inverter having 158 cells and 334 µm^2 area. The total power dissipation of 388021.953nW in that leakage power of 285.735nW and dynamic power 387736.218nW. Table 8 shows the area, number of cells and gates after detailed routing.

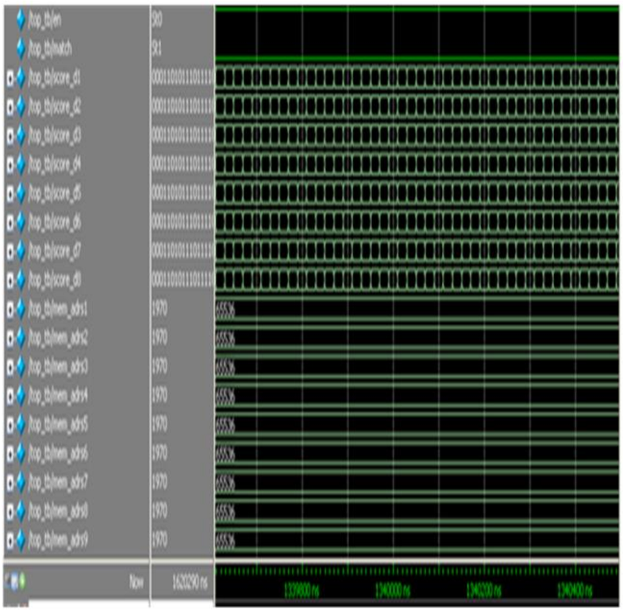

Fig.15. Simulation Results for No-Match Condition

Table 8 shows the comparative study of IWT, Overlap-add, O2D and Image enhancement technique compared between area, gate count, power dissipation and delay. The IWT technique shows better performance with respect to area, power and gate count. Fig 18 shows the comparative study of recognition rate between IWT and Overlap-add technique, IWT shows higher recognition rate than Overlap-add method.

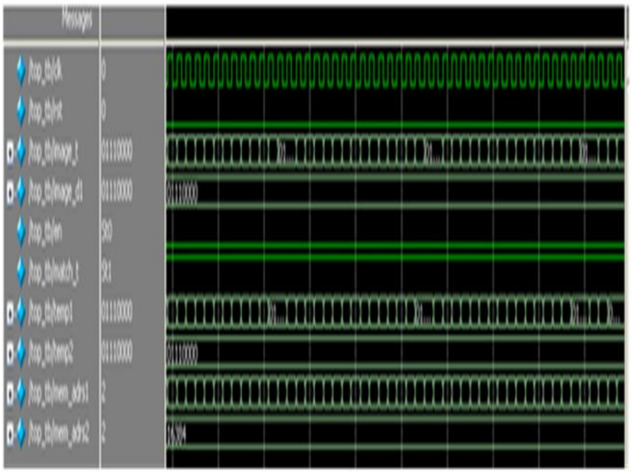

Fig.16. Simulation Results for Match Condition

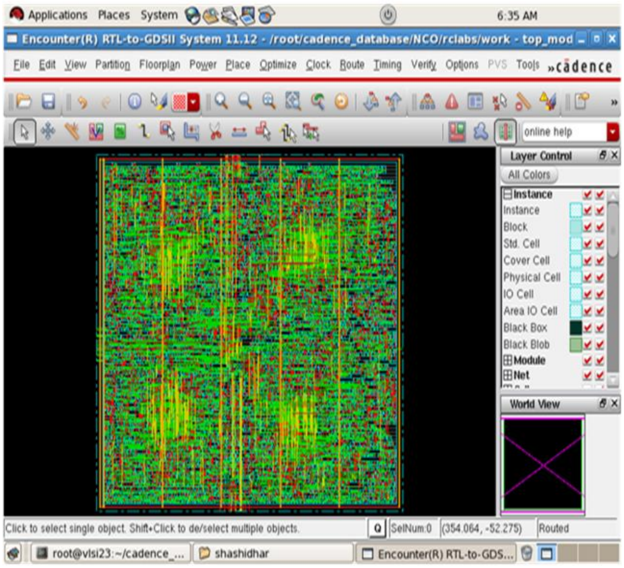

Fig.17. Final routed Cell layout of the Integer wavelet Design

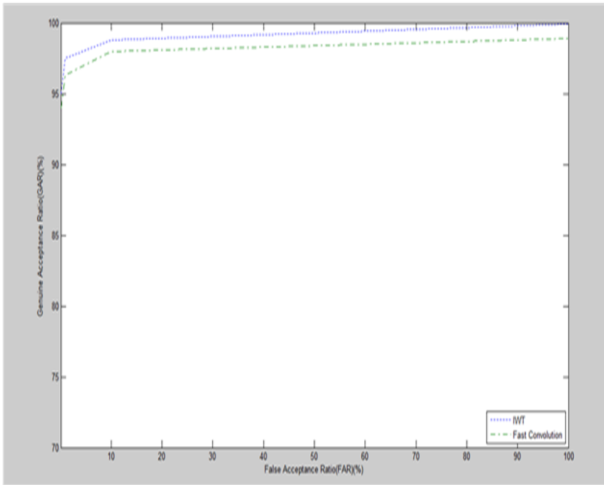

Fig.18. GAR vs FAR of overlap add and IWT

Table 6. Area Utilization Summary of Integer Wavelet Method

Instance	No. of Cells	Cell Area
Sequential	912	23701.104 μm^2
Inverter	158	334.454 μm^2
Logic	682	20235.125 μm^2
Total Area	1752	44270.683 μm^2

Table 7. Power Utilization Summary of Integer Wavelet Method

Leakage Power	285.735 nW
Dynamic Power	387736.218 nW
Total power	388021.953 nW

V. Concusion

The comparative study reveals that IWT is highly efficient compared to overlap-add Method, Image enhancement technique and O2D. The characteristics of low area, low power and low delay for IWT is shown through the ASIC Implementation of the same. It has been observed that the recognition rate of IWT is better than overlap-add method. The credibility to use both algorithms has been justified with improved recognition rate, area, power and delay, compared to other algorithms. In future, only those features in the required region of the finger can be concentrated upon and can be derived for higher recognition rate and effective ASIC implementation.

Table 8. Comparison of device parameters between different algorithms

		Overlap- Add	IWT	O2D[16]	Image Enhancement [12]
Technology/FPGA		Tsmc18.1.0	Tsmc18.1.0	Vertex-xc5vlx110t	Tsmc18.1.0
Area/LUT/Register-FF		8888.141 μm^2	6852.2 μm^2	94521	70242.49 μm^2
Gates	Sequential	1211	912	---	1744
	Unresolved	212	158	---	414
	Logic	743	682	---	6183
Delay/Speed		1565ps	1032ps	56.686MHz (Clock rate)	---

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