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DEVELOPMENT OF NOVEL ALGORITHM FOR HAAR TRANSFORM USING PAIRED TRANSFORM: IMPLEMENTATION ON TMS DSP PROCESSORS

Ranganadh Narayanam
Department of Electronics and Communications Engineering, Faculty of Science and Technology, The ICFAI Foundation for Higher Education, Hyderabad, (Deemed to be University under section 3 of UGC Act, 1956), India

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ABSTRACT

Paired transform splits the mathematical structure of many discrete unitary transforms, including the Fourier, Hadamard, Cosine and Hartley transforms, into the minimum number of short transforms. The discrete Haar transform that is very useful in many signal and image processing applications can be also calculated by the fast paired transform. The Haar transform can be considered as the particular case of the paired transforms, namely the 2-paired transform. In this research a Novel Fast algorithm for Haar transform is developed using paired transform: Paired Fast Haar Transform (Paired FHT). For illustration purposes relation between the Haar and paired transforms are described using the examples for 16, 8, 4 – point transforms are analyzed in detail. Finally the novel Haar transform: Paired Fast Haar transform is implemented using Code Compose Studio for TMS DSP processor Starter Kit (TMS DSK) TMS 320 C 6713 DSP processor for understanding the possible sampling rates.

Keywords: Haar transform, Fourier transform, paired functions and transform, wavelets, TMS DSP, Code Composer Studio.

1. INTRODUCTION

Discrete orthogonal Haar transform is widely used in speech processing, image processing, and communication. Non-normalized Haar orthogonal functions take values ±1 and 0, and the computation of the transform requires arithmetic operations of addition and subtraction only. The values of basis functions of the discrete Haar transform (DHT) are zero at many points, the matrix of the Haar transform is sparse, and that makes the transform to be very simple in computation. The complete system of the Haar transform is composed by series of shifted functions. Inside each series, the functions represent themselves the joint, identical, but different by sign impulses running on the unit interval [0, 1] by a discrete interval of time. The functions are the precise and shifted copies of each other. The resemblance property of the functions makes the Haar system of functions to be popular in wavelets [5]-[6]. In the present paper, another complete set of functions are considered, namely paired functions, that was derived by Prof. Dr. Grigoryan [Department of ECE, University of Texas San Antonio, USA] from the properties of the discrete Fourier transform [7], [9]. This system of functions reveals completely the mathematical structure of the 1-D discrete Fourier transform (DFT), when considering it as a minimum composition of the short 1-D DFTs. In other words, the paired functions split directly the complex structure of the Fourier transform into a number of separate transforms. The splitting represents itself the unitary paired transform that has a fast algorithm of calculation. The systems of paired functions are numbered by two parameters, namely, one parameter for the frequency and one parameter is the time. The change in time determines series of functions, and the total number of pairs numbering the system of functions, if such is complete, has to be equal the length of the 1-D DFT, let say N. The construction of the 1-D paired functions is performed in a way different than for the Haar system of functions [9]. Here a decomposition of the discrete Haar transform by the paired transform is described, that yields the fast algorithm for calculating the Haar transform: Paired Fast Haar Transform (Paired FHT). The application of the algorithm for 4, 8, and 16-point DHTs are considered in detail for Paired FHT. Finally to observe the number of clock cycles taken for Paired Transform based Discrete Haar Transform: Paired

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FHT, N = 8 to 1024 Paired FHT are implemented using C programming in Texas Instruments Integrated Development Environment Code Composer Studio, from N = 8 to 1024, for Texas Instruments DSP processor TMS 320 C 6713.

2. HAAR TRANSFORM

The Haar basis functions, $\mathbf{h_m(t)}$, are defined on the interval [0, 1). For N = $\mathbf{2^r}$, the basis function with number m = 0 : (N − 1) is defined as follows.

$$h_0(t) = 1$$

$$h_m(t) = \begin{cases} 2^{l/2}, & \text{if } \frac{k-1}{2^l} \le t < \frac{k-0.5}{2^l} \\ -2^{l/2}, & \text{if } \frac{k-0.5}{2^l} \le t < \frac{k}{2^l} \\ 0, & \text{for all other } t \in [0,1) \end{cases}$$

Where $m = 2l + k - 1$, $0 \le l \le r - 1$, and $0 \le k \le 2^l$.

The basis functions, $\mathbf{h_m(n)}$, of the discrete N-point Haar transformation are defined as the sampled version of the Haar functions, namely

$$h_m(n) = h_m(nT), \quad n = 0:(N-1), \quad T = 1/N$$

Example 1: Let N = 8, 4, and 2, then the following matrices correspond to the N-point Haar transformations

$$[H_8] = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ \sqrt{2} & \sqrt{2} & -\sqrt{2} & -\sqrt{2} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sqrt{2} & \sqrt{2} & -\sqrt{2} & -\sqrt{2} \\ 2 & -2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & -2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & -2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & -2 \end{bmatrix}$$

$$[H_4] = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ \sqrt{2} & -\sqrt{2} & 0 & 0 \\ 0 & 0 & \sqrt{2} & -\sqrt{2} \end{bmatrix}$$

$$[H_2] = \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix}$$

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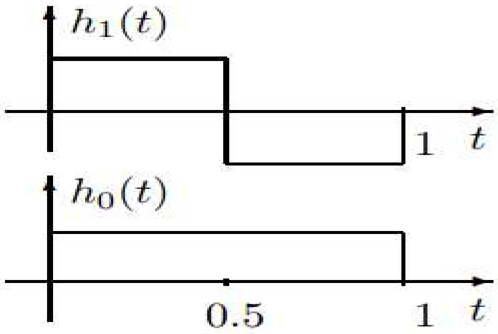
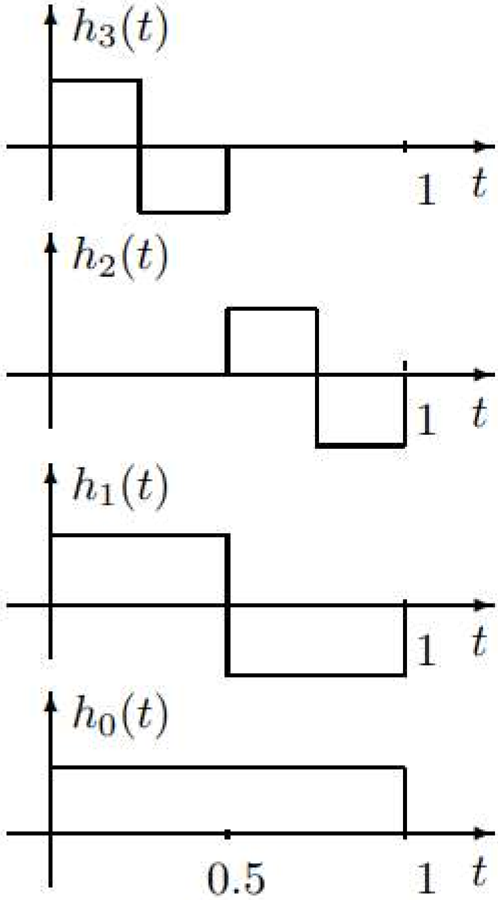
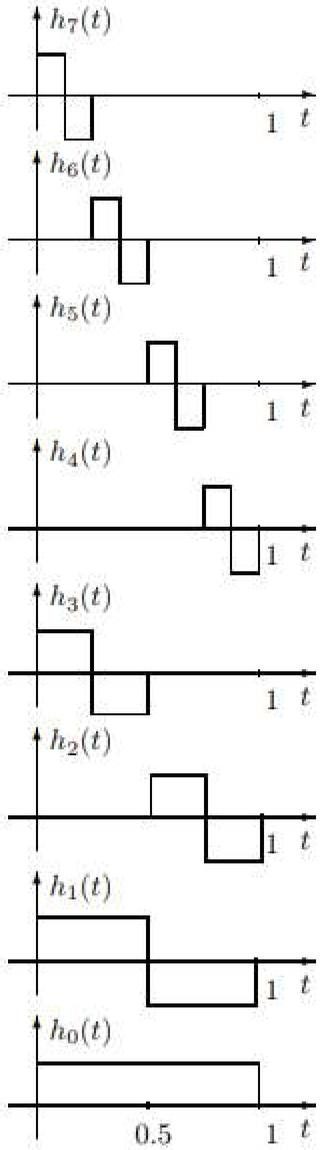


(a) The basis functions of the 2-point Haar transform
(b)



(b) The basis functions of the 4-point Haar transform



(c) The basis functions of the 8-point Haar transform
Figure 1 The basis functions of Haar Transform

Figure 1 shows the basis functions of the 2, 4, and 8- point discrete Haar transforms. One can note, that the basis functions of the N/2-point Haar transform are the first N/2 basis functions of the N-point Haar transform.

3. PAIRED TRANSFORM

Consider the concept of the paired functions that define the unitary paired transformation [9]. Let $p,t \in X$ and let $\chi_{p,t}$ be the characteristic function

$$\chi_{p,t}(n) = \begin{cases} 1; & np = t \bmod N \\ 0; & \text{otherwise} \end{cases} \quad n = 0 : (N-1) \tag{1}$$

Definition 1: Given t ∈ {0, 1, . . . , N/2 − 1} and p ∈ X, the real function

$$\chi'_{p,t}(n) = \chi_{p,t}(n) - \chi_{p,t+N/2}(n), \quad n = 0 : (N-1) \tag{2}$$

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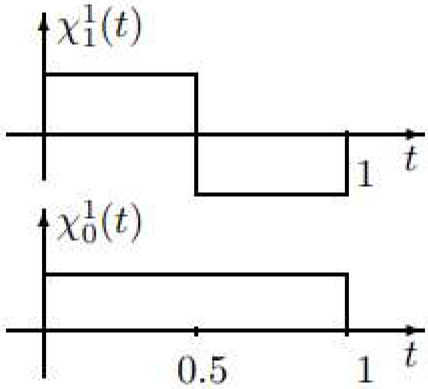
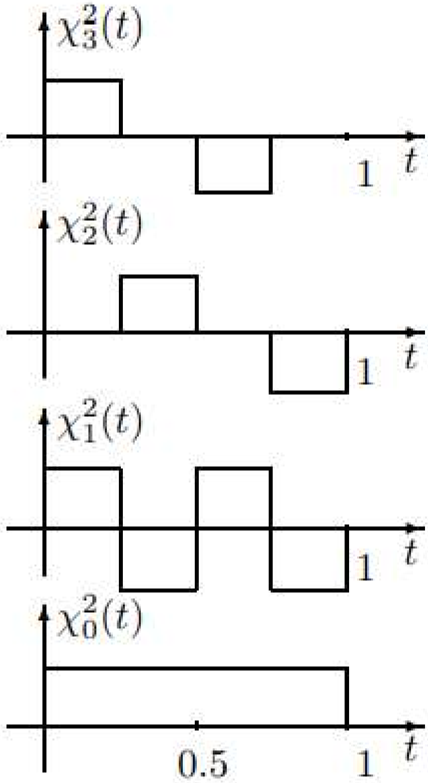
Is called a paired function. As an example, Figure 2 shows the basis functions of the 2, 4, and 8-point discrete paired transforms. According to the definition of the paired transforms [10], the basis paired functions are determined by the extremal values of the cosine functions, when they run through the interval [−1, 1] with different frequencies.



(a)The basis functions of the 2-point paired transform



(b)The basis functions of the 4-point paired transform

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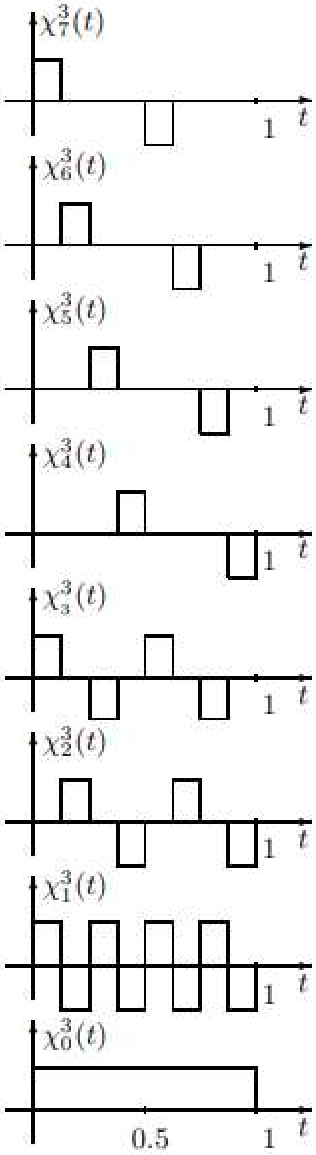

(c)The basis functions of the 8-point paired transform
Figure 2. The basis functions of the paired transform

In other words, the paired functions with indeces *p, t* can be written as

$$\chi'_{p,t}(n) = \mu\left(\cos\left(\frac{2\pi(np-t)}{N}\right)\right), \quad n = 0:(N-1) \tag{3}$$

μ is the real function that differs from zero only on the bounds of the interval [−1, 1] and takes values μ(−1) = −1 and μ(1) = 1. For $N = 2^r$, r > 1, the complete set of the basis functions is defined by pairs *(p,t)* that provides the partition of the interval of integers [0 : (N − 1)] by the sets

$$T'_p = \{(2k+1)p \bmod N;\ k = 0 : (N/2-1)\}$$

Therefore, for the basis paired functions the following definition is valid

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$$\chi'_{2^k,2^k t_1}(n) = \mu\left(\cos\left(\frac{2\pi(n-t_1)}{2^{r-k}}\right)\right), \quad (\chi'_{0,0}(n) \equiv 1) \tag{4}$$

Where $t_1 = 0 : (2^{r-k-1} - 1)$ and $k = 0 : (r - 1)$.
It can also be seen that both the transforms have the "similar" recursive formulae for constructing the matrices *(2N × 2N)* from matrices *(N × N)*. Indeed, the matrix of the paired transform χ'_{2N} can be constructed as

$$[\chi'_{2N}] = \begin{bmatrix} [1\ -1] \otimes I_N \\ [1\ \ \ 1] \otimes [\chi'_N] \end{bmatrix}, \quad [\chi'_2] = \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \tag{5}$$

Where I_N is the identity matrix $N \times N$, $N \geq 2$, and $\otimes$ is the right-hand Kronecker product.
For the *2N*-point Haar transform, the following recursive formula holds

$$[H_{2N}] = \begin{bmatrix} [H_N] \otimes [1\ \ \ 1] \\ \sqrt{N} I_N \otimes [1\ -1] \end{bmatrix}, \quad [H_2] = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{6}$$

Now it is considered an example that illustrates how to change the matrix of the paired transform in order to obtain the matrix of the Haar transform.
Example 2: Let N = 8, and let $[H_8]$ be the Haar matrix 8 × 8. Then, perform the following permutation of the columns in the matrix

$$(1) \to (1), (2) \to (5), (3) \to (3), (4) \to (7)$$
$$(5) \to (4), (6) \to (8), (7) \to (2), (8) \to (6)$$

That can be written as the permutation

$$P_c : (2, 5, 4, 7)(6, 8)$$

As a result, it is obtained the following matrix $[H_{8;c}]$

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ \sqrt{2} & 0 & -\sqrt{2} & 0 & \sqrt{2} & 0 & -\sqrt{2} & 0 \\ 0 & -\sqrt{2} & 0 & \sqrt{2} & 0 & -\sqrt{2} & 0 & \sqrt{2} \\ 2 & 0 & 0 & 0 & -2 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 & -2 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & -2 \\ 0 & 2 & 0 & 0 & 0 & -2 & 0 & 0 \end{bmatrix} \tag{7}$$

Next change the order of rows as

$$(1) \to (8), (2) \to (7), (3) \to (5), (4) \to (6)$$
$$(5) \to (1), (6) \to (3), (7) \to (4), (8) \to (2)$$

In other words, use the following permutation of rows

$$P_r = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 8 & 7 & 5 & 6 & 1 & 3 & 4 & 2 \end{pmatrix} \tag{8}$$

In the general case $N \geq 8$, the permutation P_r in (8) is the well-known *reverse shuffle* permutation [11]. After performing the permutation by rows, it is obtained the matrix that it is denoted by $[H_{8;c,r}]$

$$\begin{bmatrix} 2 & 0 & 0 & 0 & -2 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 & -2 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 & -2 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & -2 \\ \sqrt{2} & 0 & -\sqrt{2} & 0 & \sqrt{2} & 0 & -\sqrt{2} & 0 \\ 0 & -\sqrt{2} & 0 & \sqrt{2} & 0 & -\sqrt{2} & 0 & \sqrt{2} \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \quad (9)$$

This matrix is the matrix of the 8-point transform with coefficients of the normalized basis paired functions

$$[H_{8;c,r}] = diag(2,2,2,2,\sqrt{2},-\sqrt{2},1,1)^T[\chi'_8] \quad (10)$$

Where ^{T} is the operation of the transposition of the matrix, and the matrix of the 8-point discrete paired transform is

$$[\chi'_8] = \begin{bmatrix} 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 \\ 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

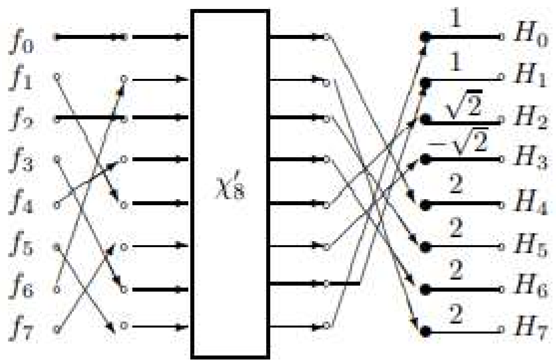

Figure 3. The flow-graph of the 8-point discrete Haar transform by the 8-point discrete paired transform

As a result, the calculation of the 8-point discrete Haar transform by the paired transform is obtained, which flow-graph is given in Figure 3. The matrix of the transform is calculated by

$$[H_8] = D[\chi_8]T$$

Where the matrix D with the weighted coefficients and matrix T of the permutation of input are defined as follows

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$$D = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & \sqrt{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\sqrt{2} & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

The calculation requires two operations of multiplication by **√2** (the multiplication by 2 is considered to be trivial). The fast $\mathbf{2^r}$ -point discrete paired transform uses $\mathbf{2^{r+1}} - 2$ operations of additions (subtractions). Thus, the calculation of the 8-point DHT requires

$$A_8 = [2^4 - 2] + 2(2) = 18$$

If consider that the operation of multiplication is realized by two real additions in the general complex case. In the real case the calculation requires 14 real additions.

To avoid the multiplication by negative coefficient **√2** in matrix D, the flow-graph of the calculation of the 8-point DHT can be changed as it is shown in Figure 4.

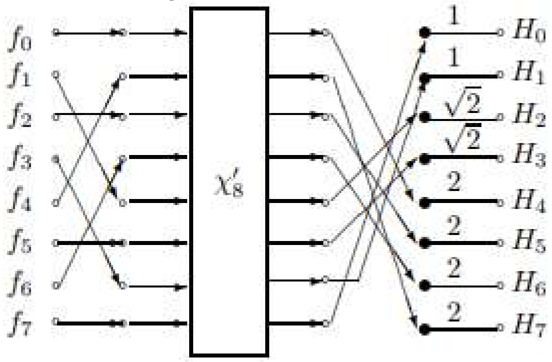

Figure 4. The flow-graph of the 8-point discrete Haar transform by the 8-point discrete paired transform

Example 3: In the case N = 4, the matrix of the Haar transformation can be written as

$$[H_4] = D[\widetilde{\chi'_4}]T$$

Where the diagonal matrix D with coefficients 1 and ± √2, the matrix of the permutation T, and the matrix $[\widetilde{\chi'_4}]$ are defined as follows

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$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \sqrt{2} & 0 \\ 0 & 0 & 0 & -\sqrt{2} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$\widetilde{\chi}_4'$ represents the paired transform whose basis functions are ordered as $\chi'_{0,0}$, $\chi'_{2,0}$, $\chi'_{1,0}$, and $\chi'_{1,1}$. In other words, such permutation Q of the basic paired functions yields the expression

$$[\widetilde{\chi}_4'] = Q[\chi_4']$$

Or

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

As a result, the following decomposition of the four-point DHT by the paired transform is obatined

$$[H_4] = D[\widetilde{\chi}_4']T = (DQ)[\chi_4']T$$

The multiplication of matrices D and Q results in the matrix

$$DQ = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ \sqrt{2} & 0 & 0 & 0 \\ 0 & -\sqrt{2} & 0 & 0 \end{bmatrix}$$

Therefore, the following representation of the four-point DHT is obtained

$$[H_4] = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ \sqrt{2} & 0 & 0 & 0 \\ 0 & -\sqrt{2} & 0 & 0 \end{bmatrix} [\chi_4'] \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Thus, the calculation of the Haar transform is reduced to the calculation of the paired transform over the reordered input, and then to reordering the output and multiplying them by coefficients of matrix D.

Figure 5 shows the flow-graph of calculating the 4-point discrete Haar transform by the paired transform χ'_4. The calculation requires two operations of multiplication by √2 and six operations of real or complex addition respectively in the real or complex case.

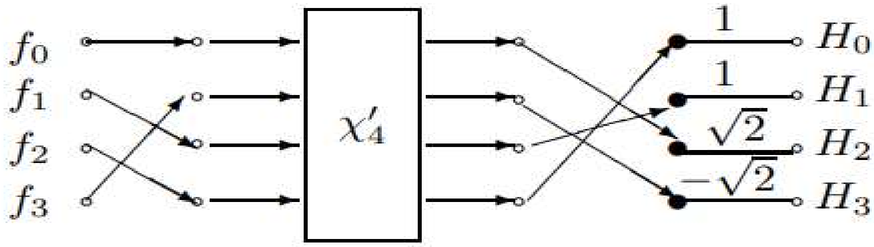

Figure 5. The flow-graph of the 4-point DHT by the 4-point discrete paired transform

The 4-point discrete Haar transform by the paired transform can be also represented by the signal flow-graph given in Figure 6. As in the N = 8 case, the change of sign of negative coefficient $-\sqrt{2}$ in the matrix D is reduced to the change of matrix of permutation T in the decomposition

$$H_4 = D[\chi'_4]T$$

As

$$[H_4] = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ \sqrt{2} & 0 & 0 & 0 \\ 0 & \sqrt{2} & 0 & 0 \end{bmatrix} [\chi'_4] \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

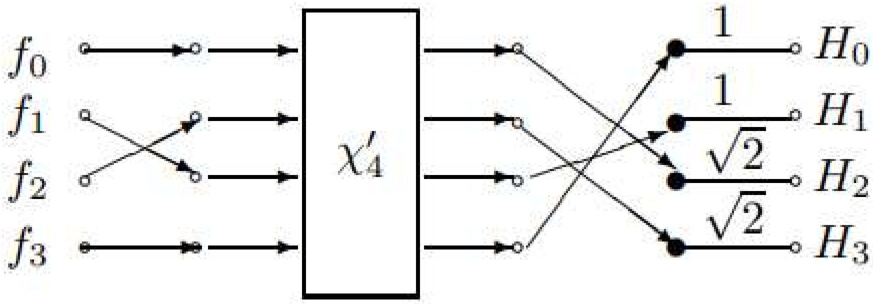

Figure 6. The flow-graph of the 4-point DHT by the 4-point discrete paired transform

Example 4: Consider the N = 16 case. The matrix of the 16-point discrete Haar transform can be decomposed as

$$H_{16} = D[\chi'_{16}]T$$

Where the matrix D of the weighted coefficients and T is the matrix of a permutation of input. The matrix D is composed from the following diagonal matrix 16 × 16.

$$diag\{1, 1, \sqrt{2}, \sqrt{2}, 2, 2, 2, 2, \underbrace{2\sqrt{2}, 2\sqrt{2}, \ldots, 2\sqrt{2}}_{8\ \text{times}}\}$$

Whose rows are rearranged in the order (16, 15, 13, 14, 9, 11, 10, 12, 1, 5, 3, 7, 2, 6, 4, 8). The matrix T relates to the permutation (2, 9) (4, 11) (6, 13) (8, 15). The decomposition $D[\chi'_{16}]T$ yields the computation of the 16-point discrete Haar transform by the paired transform, which diagram is given in Figure 7.

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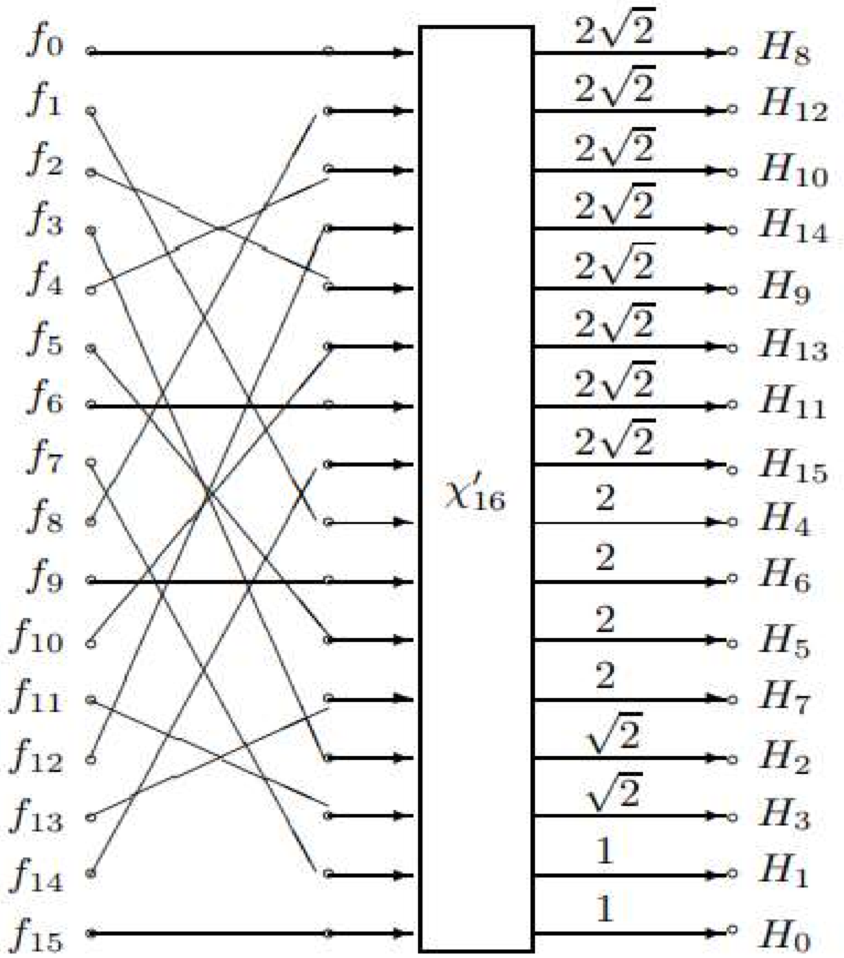

Figure 7. The flow-graph of the 16-point DHT by the 16-point discrete paired transform

Thus, the paired transform up to the permutation of columns and rows is the not normalized discrete Haar transform. Moreover, the basic functions of the Haar transform as the basic functions of the paired transform can be derived from a system of cosine functions of certain frequencies.

The paired transform is fast and therefore can be used for the fast computing the Haar transform. It can be reminded here that the paired transforms split the mathematical structure of the Fourier, Hadamard, and other transforms, being an important part of the transforms, especially in the two- and multi-dimensional cases. By this reason, it is to be considered that no comparison between the Haar and Fourier transforms is to be made, but consider the first as a transform that is compound part of the Fourier transform. The simple relation between the paired and Haar transforms shows a way how to extend the concept of the Haar transform to the orders different than power of two. And this way may be found form the constructions of the unitary paired transforms that exist for many types of orders N, not only for powers of two.

4. INTRODUCTION TO TMS 320 C6713 DSP PROCESSOR AND CODE COMPOSER STUDIO [13]

In this research the novel paired transform based Haar transform: Paired Fast Haar Transform (Paired FHT) is implemented onto TMS DSP processor TMS 320C 6713 processor. Programming done using C language, Download the program to the processor using the DSPIK software (CCS – IDE) and executed it.

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Introduction

Under reasonable constraints, a continuous time signal can be adequately represented by samples, obtaining discrete time signals. Thus digital signal processing is an ideal choice for anyone who needs the performance advantage of digital manipulation along with today's analog reality. Hence a processor which is designed to perform the special operations (digital manipulations) on the digital signal within very less time can be called as a Digital signal processor. **DSP Processors** such as Texas instruments and Analog Devices Contains CPU, RAM, ROM, I/O ports, Timer and these are Optimized for – fast arithmetic, Extended precision, Dual operand fetch, Zero overhead loop, Circular buffering.

Very important features of DSP processors are:

Fast-Multiply accumulate: used for Most DSP algorithms, including filtering, transforms, etc. are multiplication- intensive.

Multiple – access memory architecture: used for many data-intensive DSP operations require reading a program instruction and multiple data items during each instruction cycle for best performance.

Specialized addressing modes: used for efficient handling of data arrays and first-in, first-out buffers in memory. *Specialized program control:* used for efficient control of loops for many iterative DSP algorithms. Fast interrupt handling for frequent I/O operations.

On-chip peripherals and I/O interfaces: used for On-chip peripherals like A/D converters allow for small low cost system designs. Similarly I/O interfaces tailored for common peripherals allow clean interfaces to off-chip I/O devices.

Architecture of TMS 320 C6713

This TMS DSP processor comprises the central processing unit (CPU), memory, and on-chip peripherals. This family of DSPs use an advanced modified Harvard architecture that maximizes processing power with eight buses. Separate program and data spaces allow simultaneous access to program instructions and data, providing a high degree of parallelism. Such Parallelism supports a powerful set of arithmetic, logic, and bit-manipulation operations that can all be performed in a single machine cycle. The C67xx DSP architecture is built around eight major 16-bit buses: four program/data buses and four address buses. The CPU is common to all C67xE devices. The C67x CPU contains:

- 40-bit arithmetic logic unit (ALU)
- Two 40-bit accumulators
- Barrel shifter
- 17 × 17-bit multiplier
- 40-bit adder
- Compare, select, and store unit (CSSU)
- Data address generation unit
- Program address generation unit

These DSPs perform 2's-complement arithmetic with a 40-bit arithmetic logic unit (ALU) and two 40-bit accumulators. The ALU can also perform Boolean operations. The ALU uses these inputs: 16-bit immediate value. The ALU can also function as two 16-bit ALUs and perform two 16-bit operations simultaneously. The C67x DSP barrel shifter has a 40-bit input connected to the accumulators or to data memory, and a 40-bit output connected to the ALU or to data memory. The barrel shifter can produce a left shift of 0 to 31 bits and a right shift of 0 to 16 bits on the input data. The barrel shifter and the exponent encoder normalize the values in an accumulator in a single cycle. Additional shift capabilities enable the processor to perform numerical scaling, bit extraction, extended arithmetic, and overflow prevention operations. The multiplier/adder unit performs 17 _ 17-bit 2s-complement multiplications with a 40-bit addition in a single instruction cycle. The multiplier/adder block consists of several elements: a multiplier, an adder, signed/unsigned input control logic, fractional control logic, a zero detector, a rounder (2s complement), overflow/saturation logic, and a 16-bit temporary storage register (T). The multiplier has two inputs: one input is selected from T, a data-memory operand, or accumulator A; the other is selected from program memory, data memory, accumulator A, or an immediate value. The fast, on-chip multiplier

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allows the DSP to perform operations efficiently such as convolution, correlation, and filtering. In addition, the multiplier and ALU together execute multiply/accumulate (MAC) computations and ALU operations in parallel in a single instruction cycle. This function is used in determining the Euclidian distance and in implementing symmetrical and LMS filters, which are required for complex DSP algorithms.

Code Composer Studio

Code Composer is the DSP industry's first fully integrated development environment (IDE) with DSP-specific functionality. With a familiar environment liked MS-based C++TM, Code Composer allow us to edit, build, debug, profile and manage projects from a single unified environment. Other unique features include graphical signal analysis, injection/extraction of data signals via file I/O, multi-processor debugging, automated testing and customization via a C-interpretive scripting language and much more.

Code Composer features include: IDE, Debug IDE, Advanced watch windows, Integrated editor, File I/O, Probe Points, and graphical algorithm scope probes, Advanced graphical signal analysis, Interactive profiling, Automated testing and customization via scripting, Visual project management system, Compile in the background while editing and debugging, Multi-processor debugging, Help on the target DSP.

5. IMPLEMENTATION OF PAIRED HAAR TRANSFORM

The novel Paired transform based Haar transform: Paired Fast Haar Transform is implemented onto **TMS 320 C6713** using Code composer studio. Programming is done using C language. This implementation is done to understand the possible sampling rate of the transform from N = 8 to 1024 size paired Fast Haar Transform. The following Table 1 depicts the implementation results.

Table 1. The maximum possible sampling rates of the Paired Haar Transform from N = 8 to 1024 size

SNO	Size of the Paired Haar Transform (N)	Number of CCs	Total time (ns)	Sampling rate up-to
1	8	402	1786.488	4.478 MHz
2	16	874	3884.056	4.119 MHz
3	32	2060	9154.64	3.495 MHz
4	64	3050	13554.2	4.722 MHz
5	128	11413	50719.372	2.524 MHz
6	256	15290	67948.76	3.768 MHz
7	512	26140	116166.16	4.407 MHz
8	1024	80320	356942.08	2.869 MHz

Following Table 2 specifies the real time sampling rate restrictions for DSP processors due to A/D converters.

Table 2 ADCs currently available [12]

Sampling rate	Resolution (no of bits)	Maximum frequency in input signal	Power
96,000	24	48 kHz	90 mW
96,000	18	48 kHz	60 mW
96,000	16	48 kHz	40 mW
65,000,000	14	500 MHz	0.6 W
400,000,000	8	1 GHz	3 W

From Table 2 it is observed that as the frequency increases the world length of these devices decreases and therefore the accuracy and dynamic range of the input and output data decrease [12]. Power utilization also increases as the sampling frequency increases. Due to limitations of resolution and power Digital Signal Processors are restricted to approximately MHz range applications [12]. So as per the Table 1, the paired Fast Haar transform can work successfully for MHz range applications for N = 1024 transform size. So, for the current all DSP processor based applications the Novel paired transform based Haar transform : Paired Fast Haar

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transform can work successfully. These sampling rates are very highly useful for applications of speech environments (KHz) and Digital Image Processing Applications (MHz) on DSP processors [12].

6. CONCLUSION

In this Research an advanced & Novel Fast Haar Transform is developed successfully using very advanced paired transform: Paired Fast Haar Transform (Paired FHT). This is implemented on TMS 320 C6713 Texas Instruments DSP processor and sampling rates for N = 8 to 1024 are observed and those are found to be suitable for all the current real time DSP processor based applications. The efficiency of implementation of any DSP application based on this Novel Paired FHT can be improved by considering all CC studio based programming features and TMS 320 C6713 architectural features while programming.

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