Implementation of Integer Wavelet Transform on Software Configurable Processor

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Abstract--**Imaging in medicine has become so common that it is necessary that we have an image compression standard for the medical images. The JPEG 2000 standard is the latest from the JPEG group. The JPEG 2000 is more computationally intensive than the JPEG. In this work we propose a faster implementation of the integer wavelet transform used in the JPEG 2000 standard. We have implemented the integer wavelet transform on the Stretch's Software Configurable Processor (SCP). A comparison of a Pentium based implementation and the SCP based implementation was done. In our work we have found that the wavelet transform calculations took nearly 35 times less number of clock cycles on the SCP when compared to one with the Pentium implementation.**

***Index Terms*—Integer wavelet transform, Image compression, JPEG2000, Medical Imaging, Software Configurable Processor, Stretch S5610**

I. INTRODUCTION

Imaging in medicine has become so common that it is necessary that we have an image compression standard for the medical images. The JPEG 2000 standard is the latest from the JPEG group. This standard performs much better when compared to the conventional JPEG standard. Unlike the conventional JPEG which is based on the Discrete Cosine Transform (DCT), the new standard is based on the wavelet transform. The improved performance comes with a cost; and it is this cost which has affected the widespread use of JPEG 2000. The JPEG 2000 is more computationally intensive than the JPEG. Baloch et al, have proposed a Reconfigurable Array Targeting Discrete Wavelet Transform for fast implementation of the algorithm [6]. In this work we propose a fast implementation of the integer wavelet transform used in the JPEG 2000 standard.

II. BACKGROUND ON JPEG 2000

JPEG 2000 standard is a quantum leap in the field of image compression. The conventional JPEG standard uses the Discrete Cosine Transform (DCT), while the JPEG 2000 uses wavelet transform for compression. As the wavelet transform is separable, a filter bank structure is used to implement it [1], [2].

JPEG 2000 standard works with image tiles. An image is divided into non overlapping image tiles. The tiles are rectangles of any dimension [3]. But as the dimensions of the image become smaller the reconstruction becomes bad and with the increasing dimensions the processing becomes slower. Each tile is considered as an independent image and encoding is performed.

Before the quantization process can take place, preprocessing and wavelet transform is calculated [3]. First the pixel values are DC Level shifted. This is done only for the values which are unsigned. Then a component transformation is performed if color images are being used. To minimize the end effect problems it is necessary to extend the image periodically at the end point. Suppose that the sequence available is {1, 2, 3, 4, 5, 6, 7} then the symmetric periodic extension is {…3, 2, **1, 2, 3, 4, 5, 6, 7**, 6, 5….}, the bold sequence is the original sequence. At the end various levels of DWT is performed on the resulting component values independently [4].

III. IMPLEMENTATION DETAILS

A software configurable processor is one in which we can modify a part of the hardware to suite to the needs of the application. This ability of the software configuration to modify hardware is beneficial to be used for computationally intensive algorithms. The parallel architecture of the Digital Signal Processor (DSP) enables us to perform vector operations. In our work we have implemented the convolution based integer wavelet transform on the Stretch's SCP. The processor can be programmed using C language.

Here, we implemented the filter bank structure on the Personal Computer (PC) in the C language. We have used a computer with 512 MB RAM, 2.99GHz Pentium 4 processor. And then we also attempted an implementation on the processor. We used two MRI images one of head and the other of pelvis. The images used had the dimensions of 256 x 256 pixels. The program in C read the data from 'head.pic' and 'pelvis.pic' files. The original images used for the application were conventional JPEG images. These images had a depth of 8 bits i.e. each pixel was represented by 8 bits of data.

In the C program we defined two functions HCONV and GCONV to calculate the convolution results. The HCONV function was used to generate the low pass convolution results, while the GCONV generated high pass convolution results.

We carried out a profiling analysis of the Pentium based C program. In the profiling analysis we found that HCONV and

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GCONV consume a significant number of clock cycles (Fig. 1). In our work we have ported the functions HCONV and the GCONV onto the ISEF (Instruction Set Extension Fabric) of the Stretch's S5610 Processor (www.stretchinc.com).

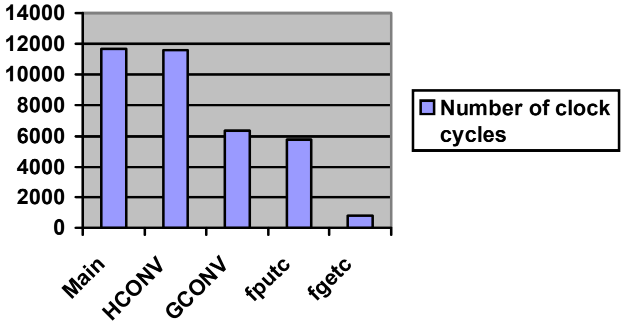

Fig. 1 Number of cycles taken by the different C functions of the Pentium Based implementation.

A.. Practical Considerations

The S5610 has 128 bit wide special registers which are used to send (or receive) data to (or from) the ISEF. These registers can hold eight 16 bit data values. The processor has four streaming functions; three of these are used to stream data into the ISEF and one is used to stream data i.e. the result out of the ISEF. The ISEF allows all the standard data types; it also allows signed and unsigned integers of variable number of bits.

B. Image and Matrix Dimensions

The JPEG 2000 is a tile based image compression algorithm. The compressing program is free to use its own tile size, but there will be problems with reconstruction if the tile size is too small and the computation will be slow if the tile size is too large. The images that we are using are 256 x 256 pixels in dimension. We have performed the wavelet transform on the complete image considering it as a single tile. Hence, the tile size that we are taking is 256 x 256. The image is read into a matrix with dimensions 256 x 260 as we will need to produce a symmetric periodic extension of the end values, on both sides, to reduce end effect problems. The original image is contained from the 3rd to the 258th column. We have extended two pixels on both sides so that we do not have any problem with the first and the last convolution result in the low-pass decomposition. Wavelet transforms are separable hence we first perform the convolution on the rows and then on the columns. After the row transformation has been performed we will have a matrix of dimensions 256 x 128 due to the down sampling of results generated. We need a matrix 128 x 260 to store the transpose of the matrix generates and to produce the symmetric periodic extension for the transposed matrix. It is very necessary to transpose the matrix as the streaming functions need the data to be in contiguous memory locations. The row operations are very fast [5]. In C the values in a row of a matrix occupy contiguous memory location; this enables us to stream data to the ISEF.

C. Width Restrictions

Since, the special registers have a finite width the data must be sent to the ISEF in steps. At one time we are sending 8 values to the ISEF. We send two arguments to the ISEF using the special registers. These arguments are the coefficient values and the pixel values. The ISEF returns the output to a special register from where it is read to a matrix.

D. Low Pass Decomposition

Table I. lists down the analysis and synthesis filter coefficients for the integer wavelet transform or the 5/3 wavelet filter as it is also called. We have calculated the wavelet transform using the convolution method and not the lifting scheme. We see from the Table I. that there are a total of 5 low-pass filter coefficients. As the impulse response also has values for negative values of *i* (independent variable); the system is non causal. As the size of the special registers is 128 bit. We can send a total of eight 16 bit pixel values. With these eight pixel values and five coefficients we can produce a total of 4 results in one call of the ISEF as shown in Fig. 2. From Fig. 2. the row with 8 sub cells represents 8 pixel values. The lower two rows represent the coefficients. When the data is sent to the ISEF the result generated is for the pixel at the first arrow. The last result generated is for the second arrow. As down sampling is required we save two results of alternate pixels, marked by bold **x**. The results marked with a 'y' are not saved. This process does not generate the convolution results for the two pixels. So, we produce the results for these pixels in the next call. We perform this process 64 times to cover up all the 256 elements in a row or column and produce 128 results after down sampling.

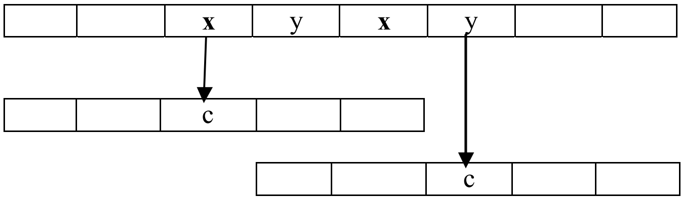

Fig 2. Low Pass Decomposition results of one call and the alignment of coefficients with pixel values

TABLE I
5/3 ANALYSIS AND SYTHESIS FILTER COEFFICIENTS

	i	0	±1	±2
Analysis Filter Cofficients	Low-Pass Filter	6/8	2/8	-1/8
	High-Pass Filter	1	-1/2	
Synthesis Filter Cofficients	Low-Pass Filter	1	1/2	
	High-Pass Filter	6/8	-2/8	-1/8

E. High Pass Decomposition

From Table I. we see that in contrast to the low pass decomposition filter which has five coefficients, the high pass analysis filter has only three coefficients. As the high pass filter also has impulse response for negative values of i (independent variable) this too is a non- causal system. From Fig. 3. it is seen that in one call 6 results are generated for the high pass filter three results are saved. We perform this 42 times which will produce 126 results and one more, 43rd time, to save only two results and not three.

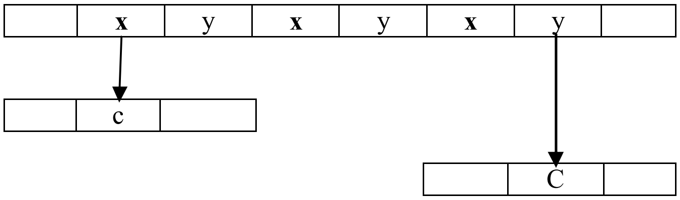

Fig 3. High Pass Decomposition results of one call and the alignment of coefficients with pixel values

F. Computational Considerations

The coefficients are not sent as real numbers to the ISEF, instead only the numerators are sent, for the low pass decomposition filter. The denominator is 8 in all the coefficients of the low pass analysis filter. Hence, in the ISEF we perform three right shift operations on the result to divide them by eight. Similarly, for the high pass analysis coefficients we pass {-1, 2, -1} so that we have a common denominator of 2 for all the results. To perform this division we shift the result to the right by one bit.

IV. RESULTS

The low pass and high pass decomposition filters were ported on the ISEF. Profiling was carried out and it was found that a total of 320 clock cycles were required to generate 256 low pass decomposition results. While in a normal C program this required 11370 clock cycles. In case of the high pass analysis it needed only 215 clock cycles on SCP while on the Pentium it took 7630 clock cycles, Fig. 4. Both the computations took nearly 35.48 times less number of clock cycles. There is a tremendous improvement in the number of cycles needed for the execution of the program. The software configurable processors will improve the performance of computation intensive processes.

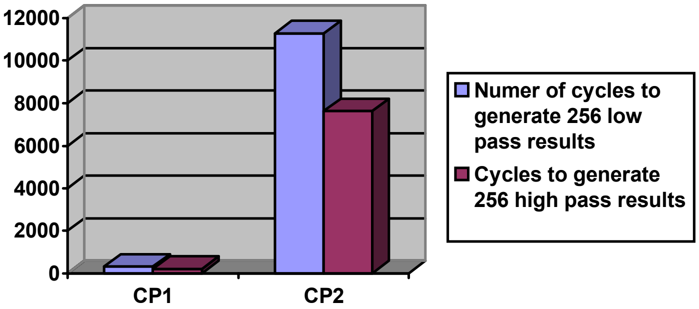

Fig. 4. Comparison between the two implementations. CP1 is the SCP. CP2 is the C implementation on a Pentium 4 CPU

Fig. 5. The Original Image of the Pelvis MRI

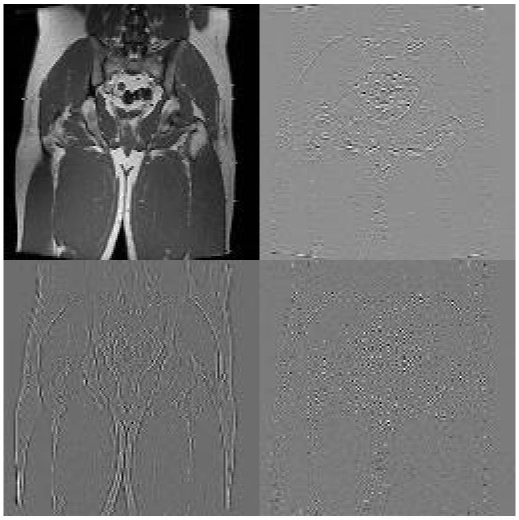

Fig. 6. The decompositions of the pelvis image shown in the Fig. 5.

Fig. 7. The reconstructed Image from the decomposition results.

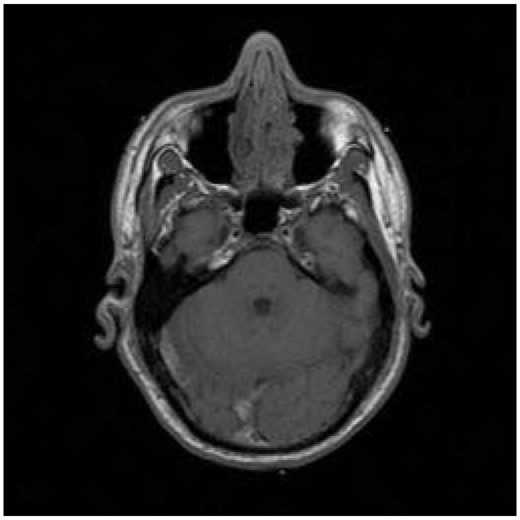

Fig 8. The original head MRI used.

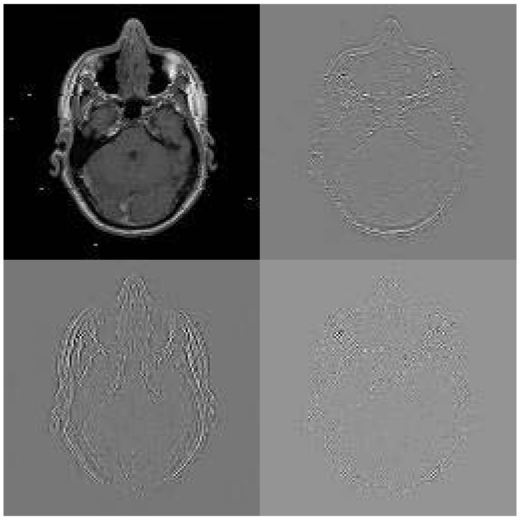

Fig. 9. The decompositions of the head MRI shown in Fig. 8.

V. ACKNOWLEDGMENT

We are grateful to Dr. Narsimha B. Bhat for providing us with opportunity to carry out this work at Manipal Dot Net Pvt. Ltd. We also thank Stretch Inc., CA, USA.

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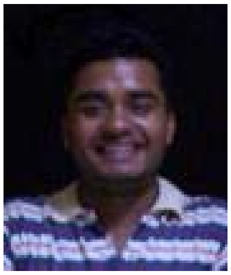

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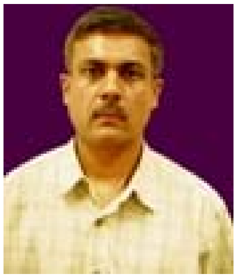

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