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Application of VLSI Framework for Image Compression Algorithms

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Abstract: - A picture or image, in its real form, include big amount of data which need not only large amount of memory required for its storage but also causes inconvenient transmission over limited bandwidth channel. Image compression decreases the data from the image in either lossless or loss way. While lossless image compression regains the real image data fully, it provides very less compression. Loss compression techniques compress the image data in variable amount depending on the quality of image required for its use in particular application area. It is performed in steps such as image transformation, measure and destruction coding. JPEG is mostly used image compression standard which uses discrete cosine transform (DCT) to transform the image from spatial to frequency domain. image contains low visual data in its high frequencies for which heavy quantize on can be done in order to reduce the size in the transformed representation. Coding follows to further reduce the redundancy in the transformed and quantize image data. Real-time data processing needs high speed which makes dedicated hardware improvement most preferred choice. The hardware of a system is favored by its low- cost and low-power implementation. These two factors are also the most important requirements for the portable devices running on battery such as digital camera. Image transform requires very high computations and complete image compression system is realized through various intermediate steps between transform and final bit-streams. Intermediate stages require memory to store intermediate results. The cost and power of the design can be reduced both in efficient implementation of transforms and removal of intermediate stages by employing different techniques. The proposed work is focused on the systematic hardware execution of transform based image compression algorithms by optimizing the framework of the system. Distribute arithmetic (DA) is a systematic approach to implement digital signal processing algorithms. DA is realized by two different ways, one through storage of pre- computed values in ROMs and another without ROM requirements. ROM free DA is more efficient. For the image transform, architectures of one dimensional discrete Hartley transform (1-D DHT) and one dimensional DCT (1-D DCT) have been optimized using ROM free DA technique. Further, 2-D separable DHT (SDHT) and 2-D DCT Architectures/Framework has been implemented in row-column approach using two 1-D DHT and two 1-DDCT respectively.

Key Words: — ***DCT(discrete cosine transform, DA(Distribute arithmetic, One dimensional discrete Hartley transform (1-DDHT) , JPEG Huffman coding.***

I. INTRODUCTION

An image in its original representation carries huge amount of data. Thus, it requires large amount of memory for storage [1]. Image compression is an important area in image processing which efficiently removes the visually insignificant data [2–8]. Compressed images are sent over limited bandwidth channel with some additional processing for robust (error free) transmission [9–12]. Transform based image compression algorithm is a most preferred choice which consists of image transform (in non-overlapping blocks), quantization of transformed coefficients and entropy coding [13]. Joint photographic expert group (JPEG) is a committee that standardizes the image compression algorithm [14]. The 8x8 block-wise two-dimensional discrete cosine transform (2-D DCT) is used as orthogonal transform in JPEG image compression [15]. Images compressed by this standard are used globally. This algorithm provides the user to choose between amount of compression and quality as per the requirement of the image in different applications. The variable amount of compression makes this algorithm very much suitable for the transmission purpose as user can adjust the bit rate of the transmission according to channel capacity.

JPEG is fixed algorithm and it has some flexibility that can be incorporated easily without any major changes in the basic structural feature [16–18]. JPEG system can be implemented in software as well as in hardware. Software solution is not promising for the applications requiring high speed. Therefore, real-time processing is done through the dedicated hardware [19,20]. In custom hardware implementation, architecture plays a vital role in deciding area, power and throughput of the design. Architecture optimizations lead to lower computational units (adders, multipliers), reduced memory size for storage of temporary variables and smaller interconnects. Architecture explorations to minimize the area and power consumption are an issue for portable devices running on battery. Low silicone area reduces the cost of the appliance and low power consumption increases the battery life time (time between recharge for chargeable battery) which in turn reduces the weight of the battery and overall size. 2-D DCT is a complex algorithm and requires high computations. Further, subsequent stages in transform based image compression require high memory storage along with arithmetic circuits. For portable devices, having image compression system (like JPEG compression in digital camera [24–27]), low-cost design, that can be achieved by reducing silicon area is highly required [28–31]. By efficiently designing the hardware architecture, image compression can be performed with low-cost and low power budget.

II. Image Representation And Classification

Image of a natural scene has infinite level of brightness and color intensity variations. Apart from intensity, they are continuous function in two dimensional space. To process the image for various applications by digital processors along with its storage in memory, image data obtained from electronic image sensors (CCD or CMOS) in digital camera, scanner or any similar device are converted into digital form by A/D converter. Sampling and quantization steps are used [1]. The infinite intensity levels of the image have now become digital having finite levels. Spatial continuity, itself being sampled by the fixed points present on the sensor, is converted to discrete. Continuous image signal (natural scene), now, is a two dimensional digital function, represented by $f(x, y)$, where the magnitude of function f represents the intensity from among finite levels of intensities at any point (x, y) in the space. The coordinate (x, y) is discrete as shown in Fig.2.1. The intensities at different points in space are called pixel elements or pixels of the image. One example of finite level of intensities can be all integral values from 0 to 255. In general, any digital image will have the fixed number of pixel elements in horizontal as well as vertical directions. The term *size* of the image is used for the total number of pixel elements in an image. It is represented by MxN, where M is the number of rows and N is the number of columns of image data.

A. Image Compression Model

Image compression reduces the amount of data from the original image representation. There are two approaches to compress an image. These are:

- Lossless compression
- Lossy compression

Image data compressed by lossless compression method can be retrieved back accurately in the reverse process called decompression. Lossless compression method has the disadvantage that images can be compressed by a maximum compression ratio of about 3 to 4 (very low compression), where compression ratio (CR) is given by,

$$CR = n1/n2$$

Here, n1 is the total number of bits in original image and n2 is the total number of bits in compressed image. In lossy compression method, an image is compressed at the cost of removing unwanted information from it which cannot be perceived by human visual system (the human eyes are not able to distinguish the changes). With the help of lossy compression technique, images can be compressed to a large extent (very high compression) subject to quality requirement for image application. Hence, lossy compression is a most common and used in many image and video coding standard such as JPEG, MPEG etc. Fig.2.2 shows a general image compression model. Image data representation has redundancy (also called pixel correlation, interpixel redundancy or spatial redundancy), in the sense, a pixel value can be predicted by its neighborhood pixels [1, 76]. De-correlation process removes the spatial redundancy and hence, facilitates compression. Some of the techniques used for this process are predictive coding, transform coding and subband coding [76]. Apart from the interpixel redundancy, there is statistical redundancy present in the data after de-correlation (not only image but any data possess statistical redundancy). This is removed by entropy encoding process where more probable symbol is assigned less number of bits and vice-versa (also called variable length encoding). Huffman coding and arithmetic coding are two important techniques used for entropy encoding of data [77], [78]. Although, arithmetic encoding gives slightly.

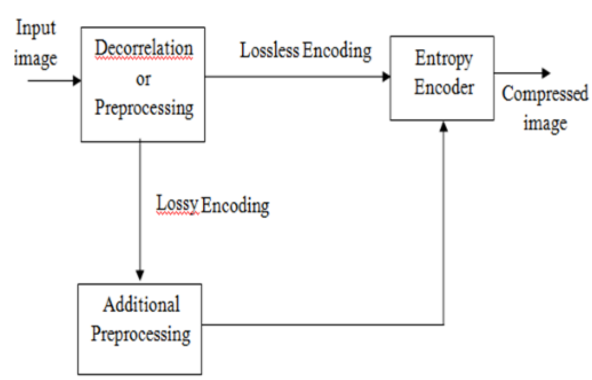

Fig.1. A generalized image compression model

III. Discrete Cosine Transform Model

DCT is an orthogonal transform. Karhunen-Lo'eve transform (KLT) is optimal in class of orthogonal transforms like

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Fourier transform, Walsh-Hadamard transform and Haar transform and has the best energy compaction [72, 79]. However, KLT is not ideal for practical image compression as its basis vectors has to be calculated according to the pixel values of the image (i.e., KLT is a data dependent). For each image, there will be separate basis vectors that also need to be included in the compressed image for the decompression process. It was found that DCT performs close to KLT and their performances are also close with respect to rate-distortion criterion (quality at different compression) [79]. In addition, there are several fast and hardware efficient algorithms available for the computation of DCT [80–87]. Therefore, DCT became the widely used transform for lossy image encoding/compression and also in the several other signal processing applications.

A. 2-D DCT Equation

For a NxN 2-D data X(i,j),0≤ i≤ N-1 and 0≤ j≤ N-1, NxN 2-D DCT is given by

$$F(u,v)=\frac{2}{N}C(u)C(v)\sum_{i=0}^{N-1}.\sum_{j=0}^{N-1}X(i,j)\times cos\frac{(2i+1)u\pi}{2N}cos\frac{(2j+1)v\pi}{2N}$$

IV. Results And Discussion

DCT has very good energy compaction. Most of the image energy is stored in few DCT coefficients. Images are transformed into 2-D DCT and images of coefficients are displayed in right side for three types of standard images as shown in Fig.1. Top left side is brighter indicating high intensity, i.e., high numerical value of coefficients, whereas, rest of the parts are black that means they have almost zero value (and hence zero energy) as energy is proportional to square of the image intensity.

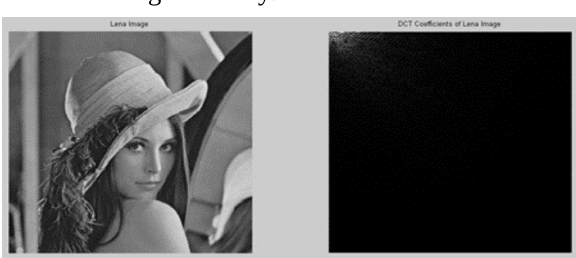

Fig.2. Energy compaction of DCT. Image (left) and its DCT coefficients' image (right) 450x450 Lena,

DC coefficient of DCT contains the average pixel values of the image. This is true for the block based transform as well. In case of block based transform, DC coefficients of each block carry most of the signal energy of that block and therefore, DC coefficients of the image have highest energy as compared to the average energy possess by total AC coefficients of entire blocks. This is shown in Fig.2, where Lena and Peppers images are first DCT transformed in 8x8 blocks. Then, AC coefficients of each block is discarded (quantized to zero) and image is reconstructed by Inverse DCT (IDCT) with the help of only DC coefficients of each block. Energy compaction property of DCT

Fig.2 Original (left) and reconstructed (right) image after quantizing all AC coefficients of 8x8 DCT to zero Lena

TABLE 1 shows the percentage improvement in compression ratio (CR) in case 2 and case 3 with respect to case 1. Shadow rows shows the CR for heavy quantization (higher value of quantization parameter i.e., "quality").

Table.1. Compression Ratio Obtained for Different Quantization Level

Images		Compression ratio in case 1 (all 64 DCT coefficients taken)	Compression ratio in case 2 (first row and first column DCT coefficients taken)	Compression ratio in case 3 (first 15 coefficients taken)	% improvement in compression ratio in case 2 (as compared to case 1)	% improvement in compression ratio in case 3 (as compared to case 1)
Lena (448x448)	quality=1	12.66	19.08	14.16	50.7 %	11.84 %
	quality=5	33.74	39.96	34.09	18.4 %	1.0 %
Peppers (512x512)	quality=1	12.50	18.17	14.02	45.3 %	12.1 %
	quality=8	41.50	45.24	41.58	9.0 %	0.1 %
Crowd (512x512)	quality=1	6.88	11.61	7.96	68.7 %	15.7 %
	quality=5	17.48	23.87	17.62	36.5 %	0.8 %
Cameraman (256x256)	quality=1	9.64	16.58	13.30	72 %	37.9 %
	quality=3	19.42	27.98	22.06	44.0 %	13.6 %

Note: "quality" is a parameter in JPEG compression which decides DCT coefficients quantization level

Higher frequencies coefficients occupy the middle place while lower are at boundaries. SDHT is tested for the performance in terms of PSNR with respect to DCT with two standard images in image compression area namely Lena and Cameraman. Images are compressed by JPEG standard principle with two modifications. In case of SDHT based transform, DCT block is replaced by SDHT and quantization matrix has been modified to quantize the SDHT coefficients as per the DCT (same numbers are used but in appropriate places). Fig.3 shows the performance curves. It can be observed that SDHT performs better in heavy quantization (at higher compression) while DCT performs better in lower compression in both types of images. Therefore, SDHT can be used for the image compression in applications requiring high compression and low hardware cost (low hardware also leads to low power consumptions) the decompressed images at very high compression and TABLE 2 shows their performance values in terms of PSNR and compression ratio.

	Lena Image		Cameraman Image	
Transform used	DCT	SDHT	DCT	SDHT
PSNR	29.44	30.83	30.53	30.95
Compression Ratio	60.88	60.54	48.71	48.93

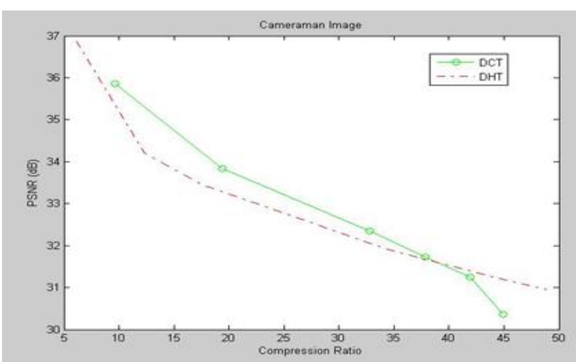

Fig.3. PSNR performance of SDHT and DCT for (a) Lena image and (b) Cameraman image

V. Conclusion

Digital image representation and its quality measurement metric have been described in this chapter. The energy compaction property of DCT has been studied by decompressing the standard images with selected low frequency DCT coefficients. High compression can be obtained when images are compressed with few lower DCT coefficients without visual distortion. An alternate transform namely separable discrete Hartley transform (SDHT) has been used for the image compression and decompression in JPEG compression procedure replacing DCT. From simulation, it is found that it performs better than DCT in high compression.

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