Implementation of Image Compression Using JPEG 2000 Algorithm in Digital Media Processor

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Abstract: *The objective of this work is to implement JPEG 2000 algorithm in Digital Signal Processor TMS320DM642 to facilitate faster processing of an image. JPEG2000 algorithm is a new standard for still image compression which provides superior low bit rate performance over JPEG. This algorithm is based on discrete wavelet transform with bit plane coding. Lossy and lossless transmission, progressive transmission by pixel accuracy and by resolution, robustness to bit errors and region-of-interest coding are some representative features of JPEG 2000 algorithm.*

Keywords: Bit plane coding, Digital Signal Processor, JPEG 2000, Wavelet transform

1. Introduction

Uncompressed multimedia (graphics, audio, image and video) data requires considerable storage capacity and transmission bandwidth. Despite rapid progress in mass storage density, processor speeds, demand for data storage capacity and data transmission bandwidth continues to outstrip the capabilities of available technologies. In order to transmit and store digital images, the images must be compressed; otherwise each image would require a huge amount of memory. Joint Photographic Experts Group (JPEG 2000) is a new standard for compression of still images. JPEG 2000 was proposed to create an image coding system for different types of images (single, multi component, bi-level images, etc) with different characteristics (natural, scientific, medical, etc). This coding system allows efficient lossy and lossless compression, superior image quality both objectively and subjectively at low bit rates. It supports compression of continuous-tone, bi-level, single-component (grayscale) and multi-component (color) images.

The existing JPEG standard is based on discrete Cosine Transform (DCT) scheme that is block based and leads to blocking artifacts at low bitrates. The JPEG 2000 based on wavelet based coding provides substantial improvements in image quality, and low bit-rate operation with rate distortion, over existing JPEG standard. The real time JPEG 2000 is being realized by high performance, large memory size. Digital Signal Processors (DSP), this project uses Texas Instruments (TI) Code Composer Studio (CCS) which is user friendly;

This paper is organized as follows. In section 2, the digital signal processor is described. The JPEG 2000 algorithm is described in section 3. The proposed work and the results are given in section 4 and the paper is concluded with section 5.

2. Digital Signal Processor

The digital signal processor TMS320DM642 evaluation module (EVM) is a low-cost standalone development platform that enables users to evaluate and develop applications for the C64xx DSP family. The EVM also serves as a hardware reference design for the TMS320DM642 DSP. The TMS320DM642 EVM features a highly integrated on-chip peripheral set which includes 3 video port interfaces, an I^2C bus controller, a multi-channel serial audio port, 64-bit external memory interface (EMIF), 10/100 Ethernet MAC controller and in addition to the high performance DSP core[8].

The high performance board features the TMS320DM642 Fixed-point DSP. The peripheral set includes three configurable video ports, a 10/100 Mb/s Ethernet MAC (EMAC), a management data input/output (MDIO) module, an inter-integrated circuit (I2C) Bus module, two multichannel buffered serial ports (McBSPs), three 32-bit general-purpose timers, a user-configurable 16-bit or 32-bit host-port interface (HPI16/HPI32), a peripheral component interconnect (PCI), a 16-pin general-purpose input/output port (GP0) with programmable interrupt/event generation modes, and a 64-bit glue less external memory interface (EMIFA), which is capable of interfacing to synchronous and asynchronous memories and peripherals.

The TMS320DM642 has cache based two level memory architecture for program and data. The TMS320DM642 core functional units are shown in Fig. 1, 8 parallel functional units that can execute instruction in parallel provides high throughput. D (D1, D2) dedicated to data load and store operations, S (S1, S2) to shift, branch, compare operations, M (M1, M2) to multiply operations, L (L1, L2) logic, and arithmetic operations. It is capable of performing 4800 million instructions per second (MIPS) running at 600 MHz CCS software tool is used to generate TMS320C6x executable files. CCS includes the assembler, linker, compiler, simulator and debugger utilities.
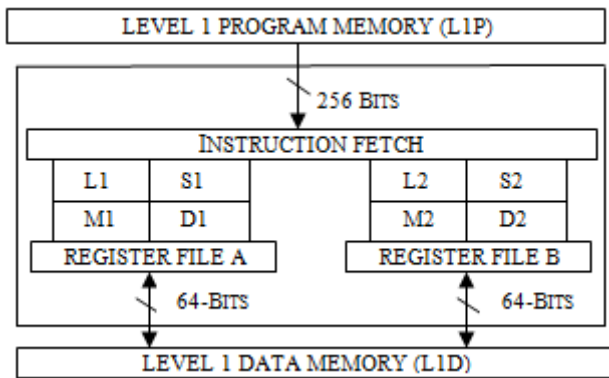
Figure 1: DSP Core architecture

3. JPEG 2000 Standard

The JPEG 2000 block diagram includes both the encoder and decoder is shown in Fig. 2. The Discrete Wavelet Transform (DWT) is applied on the input image. The transformed coefficients from the DWT block are quantized. After quantization, each subband of different decomposition levels are further divided into code blocks of smaller size. Then bit plane coding is applied separately on each code block. Each bit plane is encoded in a sequence of three coding passes namely, significance pass, magnitude pass and cleanup pass. The decoder is the reverse of the encoder.

The JPEG 2000 standard works on the image or image tiles. Image tiles refer to the partition of the input image into non-overlapping blocks. These image tiles are compressed and reconstructed independently as distinct images. All tiles have same size except the tiles which are located in the image boundary. Tiling used for reducing the memory requirements, and decoding specific portion of the image. Dimension of the image tiles affects the image quality. More tiling artifacts created by the smaller tiles compared to larger tiles (visually better). Every sample in the image tiles are DC level shifted by subtracting the quantity 2^{m-1}, m is sample precision.
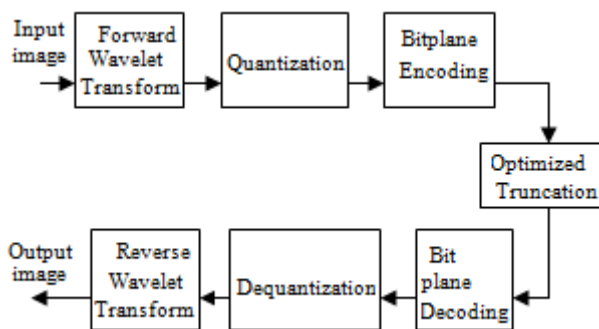

Figure 2: JPEG 2000 Block diagram

3.1. *Discrete Wavelet Transform*

Wavelet transform is mathematical tool for decomposing a signal into multi-resolution representation. In DWT, image or image tile components are decomposed into different decomposition levels [2]. Decomposition levels contain a number of sub bands which consists of coefficients. These coefficients describe the horizontal, vertical and spatial

frequency characteristics. The DWT can be reversible or irreversible. The 9-tap/7-tap Daubechies wavelet filter is used for irreversible (lossy) transform and 5-tap/3-tap integer wavelet filter is used for reversible (lossless) transform. The Daubechies 9/7 analysis and synthesis filter coefficients are given in Table I and Daubechies 5/3 analysis and synthesis filter coefficients are given in Table II.

The JPEG 2000 standard supports convolution-based and lifting-based filtering modes. For implementing both the modes the signal should be extended periodically. Convolution-based filtering is implemented by taking a series of dot products between the filter masks and the extended input signal. Lifting-based filtering is simple filtering operations, odd sample value of the signal are updated with a weighted sum of even sample values, and even sample values are updated with a weighted sum of odd sample values.

Table 1: Daubechies 9/7 analysis and synthesis filter coefficients

Analysis Filter Coefficients		
Index	*Low pass Filter*	*High pass Filter*
0	0.602949012363579	1.115087052456994
±1	0.2668641184428723	0.5912717631142470
±2	0.0782232665289878	0.0575435262284995
±3	0.0168641184428749	0.0912717631142494
±4	0.02674875741080976	
Synthesis Filter Coefficients		
Index	*Low pass Filter*	*High pass Filter*
0	1.115087052456994	0.602949012363579
±1	0.5912717631142470	0.2668641184428723
±2	0.0575435262284995	0.0782232665289878
±3	0.09127176311142494	0.0168641184428749
±4		0.02674875741080976

Table 2: Daubechies 5/3 analysis and synthesis filter coefficient

Analysis Filter Coefficients		
Index	*Low pass Filter*	*High pass Filter*
0	6/8	1
±1	2/8	-1/2
±2	1/8	
Synthesis Filter Coefficients		
Index	*Low pass Filter*	*High pass Filter*
0	1	6/8
±1	-1/2	-2/8
±2		-1/8

Lifting based filtering requires less memory, less computation and easily adapted to produce integer-to-integer wavelet transforms for lossless compression. The lifting–based filtering for the 5/3 analysis filter is performed by means of two equations (1) and (2).

The odd coefficients are given by\

$$y(2n) = x(2n) + \left\lfloor \frac{y(2n-1) + y(2n+1) + 2}{4} \right\rfloor \quad \text{\#} \quad (1)$$

Even coefficients are given by

$$y(2n+1) = x(2n+1) - \left\lfloor \frac{x(2n) + x(2n+2)}{2} \right\rfloor \quad \text{\#} \quad (2)$$

where x (n) is the given extended input sequence, y (n) is the output sequence.

3.2 Quantization

Quantization is the process of reducing the precision of the individual coefficients to reduce the number of bits needed to store the transformed coefficients. It is lossy operation for step size other than 1. Both uniform and non-uniform quantizers are used depending on the application. JPEG 2000 standard provides different step size for each subband. The quantized coefficients $q_s(u, v)$ according to the formula

$$q_s(u, v) = sign(t_s(u, v)) \left\lfloor \frac{|t_s(u, v)|}{\Delta_s} \right\rfloor \qquad (3)$$

where $t_s(u, v)$ is the transformed coefficients for each subband s, Δ_s is the step size for each subband s. The step size for subband s is calculated as follows

$$\Delta_s = 10 * \left\lfloor \frac{1}{\sqrt{2^{(2*s)}}} \right\rfloor \qquad (4)$$

The transformed coefficients are unsigned values and the quantized coefficients are signed values. Quantized coefficients are represented in sign-magnitude representation prior to coding.

3.3 Entropy coding

Each subband is divided into rectangular non-overlapping blocks of size 32*32 or 64*64 called code blocks, which form the input to the entropy coder. Code block approach reduces memory requirements in both hardware and software implementations. Code block are scanned in raster order within each subband. Each code block is coded independently without reference to the other code blocks [3]. The bit plane of a code block is visited as shown in Figure 3.

Scanning starts from top left, the first four position of the first column are scanned. Then second four position of the second column are scanned, up to the width of the code block is scanned. Then second four position of the first column is scanned and so on. Bit plane in the code blocks are coded from the least significant bit plane to the most significant bit plane. One of the three coding passes such as significance propagation pass, magnitude refinement pass and clean up pass is used to code the individual coefficient in the bit plane. These coding passes collect the contextual bit in information about the bit plane data.
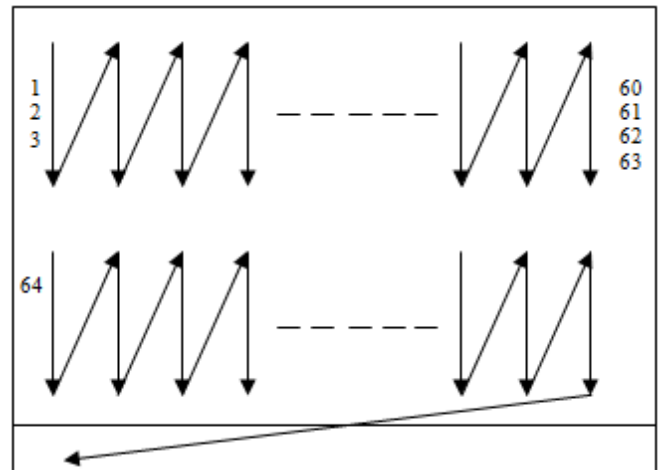

Figure 3: Scanning pattern of the code block

1) Significance propagation pass: The first coding pass for each bit plane is significance pass. This pass is used to convey significance and sign information for coefficients that have not yet been found to be significant and predicted to become significant during the processing of the current bit plane. Sign bit is coded after the sample is predicted to be significant.

2) Magnitude refinement pass: The magnitude refinement pass is second coding pass. In magnitude refinement pass, all bits which became significant in a previous bit plane are coded and also include the bits from coefficients which are previously significant except those that have just become significant in the instantly preceding significance propagation pass. The summation of the significance state of the horizontal, vertical, and diagonal neighbors is used to determine the context.

3) Clean-up pass: The final pass is the clean-up pass in which coefficients that are not significant during the previous passes and had the context value of zero in the significance propagation pass are encoded. The clean up uses the neighbor context and also uses the run-length context.

4. Results

The implementation results for four different test images *lena, barbara, rice* and *cabin* of size 128*128 and 256*256 are presented. The JPEG 2000 algorithm has been applied with lifting implementation of db 5/3 wavelet, scalar quantization with bit plane coding. The results have been taken for various test images and the corresponding reconstructed images are shown below.
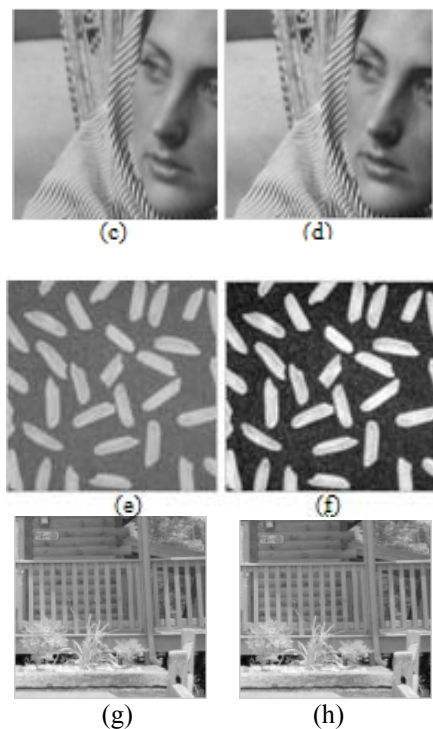
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Figure 4: Image size of 128*128 (a) Original *lena* image (b)Reconstructed *lena* image (c) Original *barbara* image (d)Reconstructed *Barbara* image (e) Original *rice* image (f) Reconstructed *rice* image (g)Original *cabin* image (h)Reconstructed *cabin* image

Fig. 4, Fig. 5 shows the input images and reconstructed images taken from the DSP kit. Here original image is reconstructed perfectly. Table III compares the results of JPEG 2000 algorithm, implemented in DSP hardware as well as MATLAB. It is seen that the results taken from the DSP kit is superior to the results from MATLAB. This implementation can be applied for real time image acquisition and transmission at different bit rates. Moreover, images acquired through camera can be compressed and transmitted or stored. The hardware implementation makes the above operations faster making it suitable for real time.
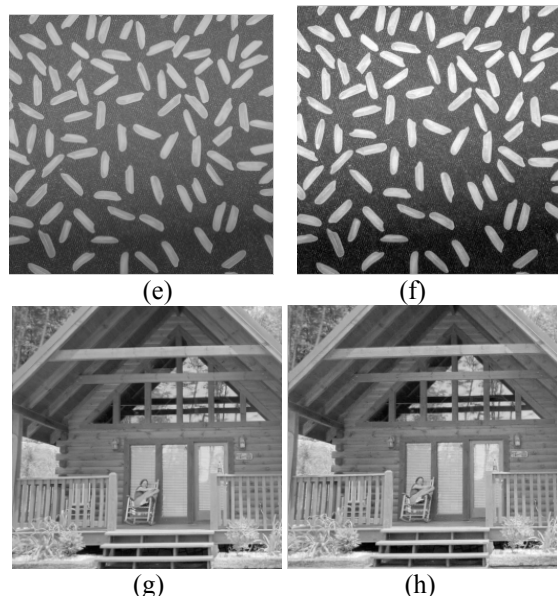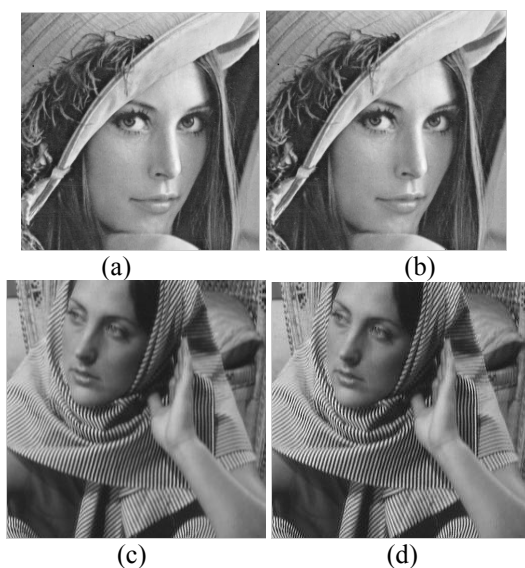

Figure 5: Image size of 256*256 (a) Original *lena* image (b)Reconstructed *lena* image (c) Original *barbara* image (d)Reconstructed *Barbara* image (e) Original *rice* image (f) Reconstructed *rice* image (g)Original *cabin* image (h)Reconstructed *cabin* image

5. Conclusion

Image compression JPEG 2000 algorithm was implemented in digital signal processor TMS320DM642 with lifting wavelet transform, Scalar quantization, and bit plane coding. JPEG 2000 supports various applications like printing, scanning, digital photography, mobile applications, and medical imagery. Lifting wavelet transform has the advantage of lesser memory consumption. Transformed coefficients were quantized using scalar quantization. Quantization allows greater compression to be achieved on the given image. Encoding process done here is bit plane coding; it is applied for each code block of fixed size. JPEG 2000 implemented in hardware facilitates faster processing of an image and also supports image acquired through the camera.

Table 3: Comparison of the results in Dsp kit and matlab

Test images	Image of size 128*128		Image of size 256*256	
	PSNR (dB) (Hardware)	PSNR (dB) (MATLAB)	PSNR (dB) (Hardware)	PSNR (dB) (MATLAB)
Lena	43.85	41.07	43.64	40.79
Barbara	44.15	41.32	44.26	41.92
Rice	43.59	40.06	43.64	40.10
Cabin	43.72	40.84	43.82	41.32

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