Progressive Coding of Trellis Coded Quantization (TCQ)

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Abstract — **TCQ has been shown to be an effective method for quantization in image compression algorithms. To support emerging image communication applications such as digital libraries, teleconferencing and remote sensing, the ability to progressively decode compressed imagery is desirable. In this paper, we describe an entropy coder that enables progressive decoding – by pixel resolution or by pixel accuracy – of wavelet transformed and trellis coded quantized imagery. The progressive decoding capabilities are provided with no loss in coding efficiency.**

I. Introduction

A Wavelet / TCQ (WTCQ) image coder with optimal rate allocation is illustrated in Figure 1. Both an M-ary arithmetic coder [1] and a Huffman coder with zero-run symbols have been used within the WTCQ system. This paper describes a bit plane entropy coder that enables progressive decoding while equaling or exceeding the performance of the M-ary arithmetic coder for fully decoded data streams. The bit plane coder has some similarities to the encoder used in CREW [2] and to the stack-run coder [3], but is designed specifically for WTCQ. In addition to lossy compression of gray scale imagery, the bit plane coder supports lossless compression of bilevel and gray scale imagery and encoding of classification maps associated with an adaptive version of WTCQ [1].

II. Bit Plane Coder

The bit plane coder supports both progressive decoding by accuracy and by resolution. The progressive by accuracy mode is described initially, followed by a description of the minor differences required to order the encoded data for progressive by resolution decoding.

The bit plane coder uses an adaptive binary arithmetic coder to encode signed integer codewords output from the TCQ. The codewords can be represented as pixels within two two-dimensional arrays - a magnitude array and a sign bit array. The magnitude array is encoded as a series of bit planes, beginning with the most significant bit plane. Each bit plane is scanned into the arithmetic coder one *sequence* at a time, where a sequence typically corresponds to a raster-scanned wavelet subband. (A subband may be further subdivided based on a classification technique described in [1]). The sequence ordering is from low to high resolution subbands. Each sequence within a bit plane is coded independently of other sequences, with the exception that the arithmetic coder probability tables for each sequence are initialized using the probability tables from the previous sequence. This (largely) independent encoding of sequences simplifies implementation of the coder, particularly in allowing progressive by accuracy and progressive by resolution coding to be nearly the same.

Sign bits are encoded using a method similar to [3] and others. The sign bit for a codeword is encoded immediately following the first non-zero bit for that codeword. As the majority of the sign bits have a value of one, this method improves the efficiency of sign bit encoding. Further, the progressive decoding efficiency is improved since sign bits are not entered into the bit stream until the point at which they will be needed at the decoder.

Coding efficiency is also improved by using multiple within-sequence context bits to choose a probability table for the bit being encoded. Two types of bits are used to determine the context - magnitude bits within the bit plane being encoded and "sign flag" bits that indicate whether or not the sign bit has been encoded for a particular pixel. Sign flag bits indicate the magnitude of neighboring pixels, including the pixel currently being encoded. They capture spatial correlation among TCQ codewords that may not be present within a single bit plane. The sign flag bits can also be non-causal with respect to raster scanning, thereby supplying information that is not available from magnitude bits within the current bit plane. A representative implementation of the bit plane coder uses ten bits to determine a context, five sign flag bits and five bits from the bit plane being encoded. Instead of having, in this case, 1024 contexts, coding efficiency is improved and memory requirements are reduced by using combinations of the ten bits to form a context. The results presented in Section 3 were obtained using ten bits to form 64 contexts.

Since the bits are encoded from most significant to least significant bit plane, the entire two-dimensional codeword array is decoded with progressively increasing precision. In progressive by resolution mode, the encoded bits are ordered such that all planes of the lowest resolution sequence are encoded, followed by all planes of the next higher resolution sequences, until all sequences are encoded. Other than this different ordering, all other aspects of the encoder are identical to progressive by accuracy encoding. Decoding is done to full precision for sequences in order of increasing resolution.

III. WTCQ Performance

An example of progressive decoding by accuracy is provided in Figure 2. PSNR for progressive decoding of an image encoded at 1.0 bpp is compared to full decoding of the image encoded at various rates. Results are also provided for progressive decoding of an image encoded at 0.5 bpp. Progressive decoding always results in an image with lower PSNR than attained for full decoding at a given rate. This is a consequence of the optimal rate allocation and of the reduced-precision inverse TCQ. Nonetheless, the partially decoded file has image quality sufficient for many progressive transmission applications, while the quality of the fully decoded image is comparable to the best available techniques. Table 1 compares fully decoded WTCQ to other high performance image coders, SFQ

[5], and SPIHT [4, 5]. All results in Table 1 used the (10,18) filters of [3]. The WTCQ results were obtained using a 3 level uniform decomposition followed by 2 decompositions of the reference band ("3+2").

To implement lossless encoding of gray scale imagery using WTCQ, a residual image is entropy encoded and appended to the lossy encoded file. The residual is converted to a sign–magnitude representation, and bit planes of the residual image magnitude are encoded from most to least significant. Sign bit encoding and contexts are identical to the lossy mode. Table 2 shows that the lossless coding efficiency of this method is comparable to [2]. Thus, the performance of WTCQ with a progressively decodable bit plane entropy coder exhibits excellent performance both at low bit rates and for lossless coding.

References

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Table 1: PSNR Results for Fully Decoded Barbara Image

Method	Decomposition	PSNR (dB)		
		0.25 bpp	0.5 bpp	1.0 bpp
WTCQ	3+2	29.66	33.51	38.21
SFQ	Wavelet Packet	29.67	33.51	37.96
SPIHT	Wavelet Packet	29.36	33.07	37.71

Table 2: Bit Rates for Lossless Coding

Method	Image		
	lena	CT	X_Ray
CREW	4.35	4.11	6.06
WTCQ	4.41	4.10	6.16

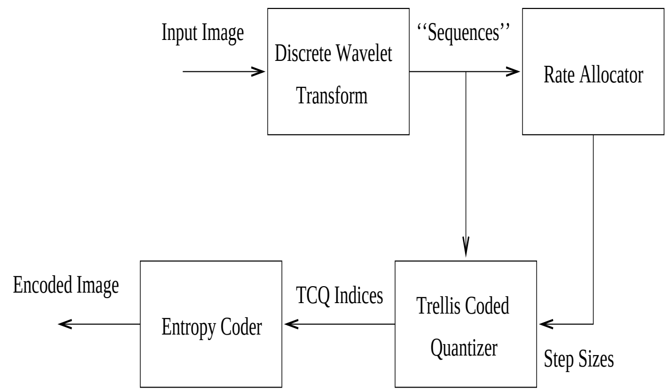

Figure 1: Block Diagram of the WTCQ coder.

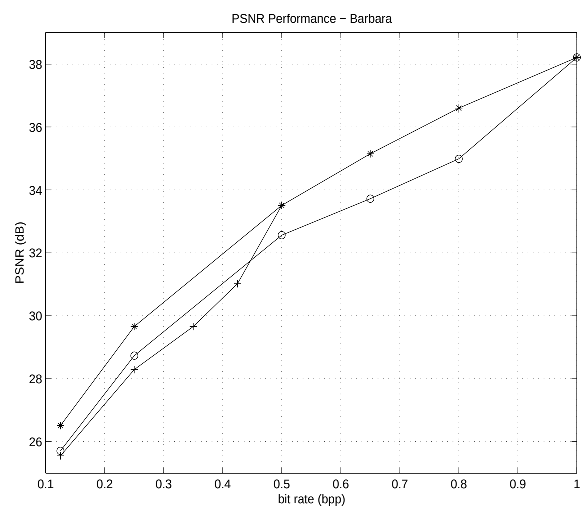

Figure 2: Progressive Decoding of Barbara.