

Super High Definition Image Coding Using Successive Approximation Wavelet Vector Quantization

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ABSTRACT

A method of coding super high definition (SHD) still images based on vector quantization of wavelet coefficients is proposed. In this coding technique, each block of wavelet coefficients is coded by a series of vectors of decreasing magnitudes, resulting in a successive approximation process. It also exploits the structural similarities among the bands. This provides efficient coding together with the ability to guarantee arbitrary distortion levels for each band, which can be exploited to achieve optimum bit allocation. Since SHD images must have high quality, they must be compressed without any visible picture quality deterioration. Due to the huge amount of image data involved, simplicity of the coding system is important to maintain acceptable processing times. Also, a hierarchical structure is desirable to provide compatibility with other existing lower resolution formats, like in multimedia applications. We demonstrate that the proposed method meets these requirements. Conventional image compression techniques such as transform, subband and vector quantization have already been tested for the coding of SHD images. Simulation results show that the proposed method achieves excellent coding performance and it outperforms other SHD image coding methods reported so far by more than 7 dB.

INTRODUCTION

There has been an increasing interest on super high definition (SHD) images, mainly due to the growing demand for high quality electronic imaging [1]. Following a discussion on the quality requirements of SHD images, a baseline SHD image format has been selected as a 60 Hz non-interlaced 2048x2048 pixel resolution 24 bits/pixel full color image. A simple estimate of the amount of data needed for the storage or transmission of a single SHD image frame is 12 Mbytes. This clearly shows that

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data compression will be an essential element of any SHD imaging system.

Among the basic requirements that a compression system designed for SHD image coding should satisfy are:

- (i) Picture quality should be perceptually transparent with a compression ratio greater than 10:1 [1],
- (ii) Computational complexity of the coding system must be minimum, due to the large amount of data to be processed, and
- (iii) The coding system should be hierarchical, in order to guarantee compatibility between the SHD and other existing lower resolution image formats (i.e. multimedia applications).

The performance of conventional image coding methods, such as transform, subband and vector quantization, has been reported for coding SHD images. In general, these coding methods give similar peak-signal-to-noise ratio results [1, 2]. Nevertheless, there are certain drawbacks related with these methods that can be pointed out. For example, DCT-based algorithms can introduce block distortion which is unacceptable in high picture quality applications. On the other hand, the use of VQ in high-quality image coding requires very large codebooks, which typically lead to an unaffordable increase of complexity.

In this paper we propose a new coding method for SHD image coding, based on Successive-Approximation Wavelet Vector Quantization (SA-W-VQ). In SA-W-VQ, each vector of wavelet coefficients is coded by a series of vectors of decreasing magnitudes [3]. Also, the structural similarities among the bands of same orientation are exploited in order to generate zero-tree roots, which increases the efficiency of the coder.

SUCCESSIVE APPROXIMATION WAVELET VECTOR QUANTIZATION

A wavelet transform is the decomposition of a signal into expansions and translations of a mother function $\psi(t)$.

It can be implemented via an octave band subband analysis/synthesis process. Wavelet transforms have been very popular for image coding applications. They provide a tool for image data decorrelation, resulting into a set of coefficients that can be coded more efficiently than the original pixel values. The wavelet transform performs analysis of a signal in the frequency domain. This property can be exploited in image coding, so that bit allocation among the wavelet coefficients can be done according to the human visual system sensitivity (HVS) to each of the frequency bands, also known as *noise shaping* [4]. Therefore, in order for a wavelet coder to achieve this bit allocation, it is convenient that an arbitrary level of distortion can be set for each band. Another important issue in the design of a coder for wavelet coefficients is the level of quantization error introduced to each individual coefficient. The overall picture quality can be significantly affected by a poorly quantized coefficient, because the wavelet synthesis process spreads this error over an area of the image [5].

Considering also that efficiency dictates that zero-tree roots have to be exploited in wavelet coding, three very important requirements for a wavelet image coder can be summarized as follows:

- (i) structural similarities among the bands of same orientation;
- (ii) noise shaping, where an arbitrary level of distortion must be set for each band;
- (iii) control over the maximum level of quantization error made in each wavelet coefficient.

It is important to point out that, in SHD image coding, since perceptually transparent image quality is required with maximum compression, these requirements acquire special importance. It will be shown that SA-W-VQ satisfy these requirements, and indeed is a very efficient method for SHD images.

Successive approximation vector quantization [3]

An important element of SA-W-VQ is the coding of the significant wavelet coefficients through successive passes. More specifically, vectors of wavelet coefficients are successively refined, so that at each pass the residual quantization error of the previous passes is further coded. Successive refinement of the residual errors continues until a certain distortion is achieved, or the bitrate budget is exhausted.

Successive approximation using k -dimensional vectors can be performed following the process illustrated in figure 1. In this approach, a vector \vec{v} is approximated by a series of vectors of decreasing magnitudes $\{\alpha^j \|\vec{v}\|, j = 1, 2, \dots\}$ where $\alpha < 1$. It can be shown that if, at each pass, the maximum error in orientation is θ_{\max} ,

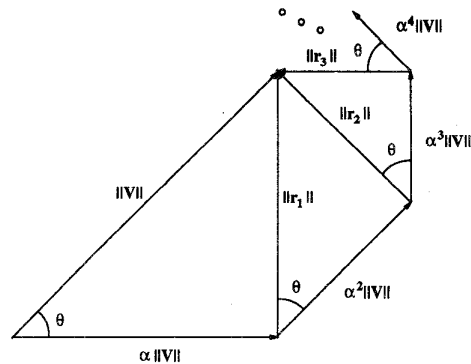


Figure 1: Analysis of convergence of the vector successive approximation

the scheme will converge (i.e. $\|\vec{r}_n\| \rightarrow 0$ as $n \rightarrow \infty$) if the values of α and θ_{\max} satisfy some relations. That is, for each value of θ_{\max} , there is a value $\bar{\alpha}$ such that the scheme will converge for each value of $\alpha \geq \bar{\alpha}$. It has been shown that the value of $\bar{\alpha}$ increases with θ , as well as the number of iterations required for convergence. Therefore, since more iterations would require more bits to achieve a certain distortion, the main requirement in the design of an orientation codebook is to provide a fairly low value of θ_{\max} . It has been found that codebooks built based upon regular lattices [6] are a good choice for the orientation codebook of this scheme. Lattice codebooks can offer a good trade off between θ_{\max} and the codebook population, due to their space packing properties. Moreover, regular lattices offer the advantage of simple and fast encoding algorithms, which can be vital in super high definition image coding.

SUPER HIGH DEFINITION IMAGE CODING USING SA-W-VQ

In this section, the application of SA-W-VQ in coding of super high definition images is addressed, and the coding system used in our experiments is described.

The two-dimensional wavelet transform used in this work is an octave band decomposition applied both to the rows and columns of an image. It is implemented by the biorthogonal filter bank **6.b5.ra7** described in [5], which was shown to give good subjective performance for wavelet transform coders.

Optimum bit allocation One of the main advantages of SA-W-VQ is that, due to the successive approximation process, arbitrary levels of distortion can be set to each band. This enables us to perform noise shaping [4] of the wavelet coefficients according to a certain human visual system (HVS) response in a straightforward way. This is because the distortion can be set in each band so as to match a desired error spectrum characteristic. This is

very important in SHD image coding, since the coding distortions must not be visible. SA-W-VQ can take full advantage of the HVS characteristics.

Lattice-based orientation codebook As has been mentioned above, lattice codebooks are a very good choice for the orientation codebook in a successive approximation vector quantization process. Several lattice codebooks have been tested and compared; it was found that the Barnes-Wall lattice Λ_{16} offers the best rate-distortion results. In our experiments, the orientation codebook is built by the second spherical shell of Λ_{16} , which consists of 4320 codevectors. The maximum angle θ_{\max} for Λ_{16} -shell 2 has been calculated to be 47° [3].

Zero-tree roots An important property of a two-dimensional wavelet transform is that, despite the low correlation among bands, there exists a strong structural similarity among the bands of the same orientation. This implies that the zero valued coefficients of the bands of same orientation tend to be in the same corresponding positions. This similarity can be exploited to produce a zero-tree root, where a single symbol indicates that one coefficient and all its corresponding ones are zero [7]. The coder described next makes use of this property.

Description of the coder In SHD image coding using SA-W-VQ, first the image mean is extracted. In our simulations, a 4 stage biorthogonal wavelet transform is then applied to the zero-mean image. The wavelet coefficients are weighted according to the assumed HVS response. Each band of wavelet coefficients is partitioned to k -dimensional blocks.

Next, the maximum magnitude V of all input vectors is computed. Initially, the reference magnitude ℓ of the codevectors is set to αV , where the value of α is chosen according to the θ_{\max} value of the selected lattice codebook. All the vectors are scanned, and the ones with magnitudes smaller than ℓ are set to zero. Each of the remaining vectors is replaced by its closest orientation codevector scaled with magnitude ℓ . After this pass, the locations of the zero vectors are transmitted. This is done via 3 symbols: zero (Z), zero tree root (ZT) and coded value (C). If a vector is zero and all of its corresponding vectors in the higher bands of the same orientation are also zero this vector is replaced by a ZT , so that it is not necessary to transmit its corresponding vectors. For the lowest frequency band, a ZT implies that the corresponding vectors in all bands are zero. In case that a vector is zero but not a ZT , it is marked as Z , and no information can be inferred about its corresponding vectors. On the other hand, a non-zero vector is replaced by a coded value symbol (C).

The string generated by the three symbols (ZT , Z and C), is then coded by the arithmetic coder described in [8] with an adaptive model. In the higher frequency bands, since there are no ZT 's, the arithmetic coder uses a model with only 2 symbols (Z and C). After encoding this string, which indicates the location of the zero vectors, the orientation codevectors of the non-zero vectors (marked as C) are encoded. For this purpose, the model of the arithmetic coder is reinitialized to have as many symbols as the population of the orientation codebook. The reference magnitude ℓ is then updated through multiplication by α . The difference between the original and the non-zero reconstructed vectors is coded using the new reference magnitude. The new orientation codevectors are also encoded into the bitstream via the arithmetic coder.

In the next pass the vectors which were previously found to be zero are scanned again. A new string of Z 's, ZT 's and C 's is encoded into the bitstream. In order to reduce the number of symbols in this string, it is beneficial to obtain as many ZT 's as possible. To achieve this, the vectors that have been found non-zero so far are assumed to be zero during the ZT generation, although they are not encoded as Z . As in the previous pass, the indices of the C vectors are encoded and the whole process is repeated until a certain bitrate is achieved.

The generated bitstream has a header, which informs the decoder about the number of stages of the decomposition, the image dimensions, the format of the image, the image means (luminance and both chrominances) and the initial value ℓ of the reference magnitude. In our implementation 10 bytes are used for monochrome and 12 bytes for color images.

EXPERIMENTS - SIMULATION RESULTS

In this section, the performance of Successive Approximation Wavelet Vector Quantization (SA-W-VQ) for data compression of Super High Definition Images is evaluated and compared with simulation results reported in the literature. For our experiments we have used the very high quality image test set retrieved from the Center for Image Processing and Integrated Computing at the University of California at Davis, namely, PORTRAIT, X-WINDOWS, GIRL WITH COLOR CHECKER and GLASSES. These are RGB color images at resolution $2048 \times 2048 \times 24$, and they were produced by NTT, Japan. For coding purposes, the original RGB images are converted into YUV format and rate-distortion curves are generated only for the luminance signal (Y).

The coding performance of SA-W-VQ is compared with that of other algorithms for the compression of Super High Definition Images. For the purpose of this comparison, we have used the luminance signal (Y) of the test image PORTRAIT, since simulation results from various SHD image coders have been reported

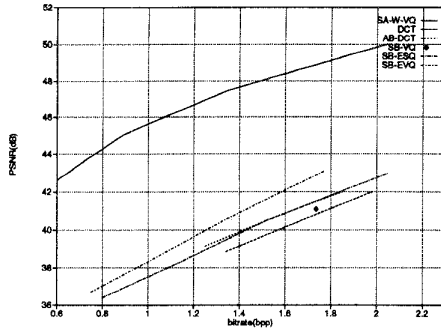


Figure 2: Comparison of SA-W-VQ with several other SHD image coding methods for PORTRAITS

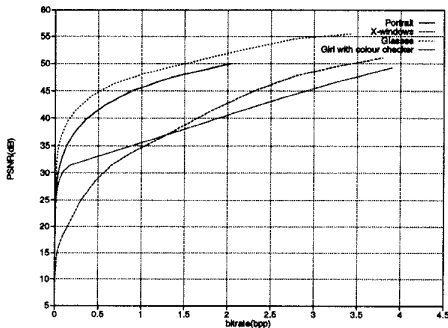


Figure 3: Rate distortion curves for the four test images coded with SA-W-VQ

for this particular image. Figure 2 gives the rate distortion results obtained by SA-W-VQ for PORTRAIT, together with those of the Scene Adaptive DCT, Variable Block Size DCT, subband Multi-Stage VQ [1], subband Entropy Scalar Quantizer and subband Entropy Vector Quantizer [2]. It can be seen that SA-W-VQ achieves a remarkably good performance, outperforming the best of these coders by almost 7 dB for PORTRAIT, as can be seen from figure 2. Due to the use of lattice codebooks, this is accomplished maintaining a very simple implementation which can be suitable for real time applications.

In figure 3 the rate distortion curves for the luminance of the SHD test set are shown. It can be seen that SA-W-VQ performs consistently for all four test images.

CONCLUSIONS

In this paper the problem of data compression of Super High Definition Images is addressed. SHD image coding requires a very high picture quality together with compression ratios more than 10:1. Moreover, simplicity of the coding system is desirable, due to the huge amount of image data to be processed.

A new coding method based on vector quantization of wavelet transform coefficients, referred to as Successive Approximation Wavelet Vector Quantization was tested for SHD image coding. SA-W-VQ provides an efficient image coder together with subjectively optimum bit allocation, which enable us to achieve high picture quality and compression ratios. Yet, this is accomplished with minimum complexity due to the use of lattice vector quantization.

Compression ratios of the order of 40:1 can be obtained without any noticeable distortion. For the test image PORTRAIT, SA-W-VQ outperforms all other coding systems reported so far by more than 7 dB. By considering the advantages of the proposed method and evaluating its coding performance, SA-W-VQ stands as an excellent data compression method for SHD still images.

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