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# Lossless Image Coding Using Conditional Entropy Constrained Vector Quantization

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**Abstract:** Lossless coding guaranties that the decompressed image is absolutely identical to the image before compression. This is an important requirement for some application domains, e.g. medial imaging, where not only high quality is in demand, but unaltered archiving is a legal requirement. In this study an entropy constrained vector quantization is proposed for lossless compression of image. The method consists of first quantizing the input image using conditional entropy constrained vector quantizer and then coding the residual images using entropy coder. Experimental results show that the new method outperforms standard entropy constrained vector quantization to achieve lossless compression while also requiring lower encoding complexity and memory requirements.

**Key words:** Lossless compression, vector quantization, entropy-constrained

## INTRODUCTION

Most data that is inherently discrete needs to be compressed in such a way that it can be recovered exactly, without any loss. The design of a data compression system consists of two distinct stages: the modeling and the coding. In the modeling part the structure is selected which determine way the events are to be conditioned and then relative frequencies of the conditioned events are gathered. The coding is easily implemented on all sources, stationary or no t and the complexity of the model has no effect on the coding unit (Langdon and Rissanen, 1982). Lossless compression requires that the reproduced reconstituted bit stream be an exact replica of the original bit stream. Examples include text, experimental results, statistical database and images. The useful algorithms recognize redundancy and inefficiencies in the encoding and are most effective when designed for the statistical properties of the bit stream.

Lossless compression schemes can be crudely classified as follows:

- Predictive schemes with statistical modeling, in which differences between pixels and their surround are computed and their context modeled prior to coding,
- Transform based coding, in which images are transformed into the frequency or wavelet domain prior to modeling and coding.
- Dictionary based schemes, in which strings of symbols are replaced with shorter (more probable) codes.
- Ad hoc schemes (such as run length encoding).

**Lossless coding techniques:**

- Run length encoding
- Huffman encoding
- Entropy coding (Lempel/Ziv)
- Area coding

Run length coding is easily implemented, either in software or in hardware. It is fast and very well verifiable, but its compression ability is very limited.

The basic idea in Huffman encoding is to assign short codewords to those input blocks with high probabilities and long codewords to those with low probabilities. The compression ratio achieved by Huffman encoding uncorrelated data becomes something like 1:2. On slightly correlated data, as on images, the compression rate may become much higher, the absolute maximum being defined by the size of a single input token and the size of the shortest possible output token (max. compression = token size [bits]/2[bits]). While standard palletized images with a limit of 256 colors may be compressed by 1:4.

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There is a wide range of so called modified Lempel/Ziv coding. These algorithms all have a common way of working. The coder and the decoder both build up an equivalent dictionary of Meta symbols, each of which represents a whole sequence of input tokens. If a sequence is repeated after a symbol was found for it, then only the symbol becomes part of the coded data and the sequence of tokens referenced by the symbol becomes part of the decoded data later. As the dictionary is build up based on the data, it is not necessary to put it into the coded data, as it is with the tables in a Huffman coder. This method becomes very efficient even on virtually random data.

**Huffman vs. entropy coding:** A Huffman encoder takes a block of input characters with fixed length and produces a block of output bits of variable length. It is a fixed-to-variable length code. Lempel-Ziv, on the other hand, is a variable-to-fixed length code. The design of the Huffman code is optimal (for a fixed block length) assuming that the source statistics are known a priori. The Lempel-Ziv code is not designed for any particular source but for a large class of sources. Surprisingly, for any fixed stationary source, the Lempel-Ziv algorithm performs just as well as if it was designed for that source. Mainly for this reason, the Lempel-Ziv code is the most widely used technique for lossless file compression.

Area coding is an enhanced form of run length coding, reflecting the two dimensional character of images. This is a significant advance over the other lossless methods.

**Vector quantization with lossless:** Vector quantization is a lossy process so, why this lossy compression technique used to achieve lossless? It's a fact that quantization often produce a structure where high order statistical dependencies can be exploited. Moreover the output of quantizer can be made smaller than that of the original signal; the complexity of high order statistical modeling is reduced. This is especially the case when structurally constrained quantizers are employed (Yu *et al*., 1994).

Entropy coding is now being used frequently in conjunction with vector quantization for image coding. Its use is motivated by the fact that the probability distribution of VQ coded images is generally skewed or non-uniform. While the average bit rate can most often be reduced by entropy coding the VQ codewords, improvement in the rate distortion performance is usually attainable by embedding the entropy coding in the design process such that both the VQ codebook and entropy coder are optimized jointly (Kossentini and Wilson, 1996).

## MOTIVATION

The advantage of residual VQ over other VQ methods (Faouzi and Mark, 1995), is achieved mainly by exploiting the statistical dependencies among the VQ stages. The hybrid technique of quantization and entropy coding of the residual signal has been shown to give up good compression performance.

RVQ, at subsequent stages, input residuals are quantized and output residuals are computed, leading to successive refinement in the accuracy of the overall representation. Each stage VQ index or symbol is then mapped into a variable-length codeword based on probabilities that are conditioned on previous stage output.

This method outperforms standard-constrained residual vector quantization while also requiring lower encoding complexity and memory requirements.

Entropy constrained residual vector quantization (EC-RVQ) has been shown to be a competitive compression technique. Its design procedure is an iterative process which typically consists of three steps: encoder update, decoder update and entropy coder update.

An adaptive arithmetic coder was used to encode the output of stage RVQ's and the residual images, the comparison ratios were slightly larger. Even better compression performance may be attained by using larger vector sizes and exploiting any statistical dependencies between the multistage images and the residual one. The entropy is used as a measure so that the comparison was fair. Preliminary experimental results are encouraging further study.

Like EC-VQ, EC-RVQ is memoryless vector quantizer. This is because the EC-RVQ design algorithm minimizes the distortion subject to a constraint on the first order or zero order conditional entropy of the vector quantizer output (Kossentini and Wilson, 1996).

## PROPOSED FRAMEWORK

We have designed a lossless image compression CEC-VQ architecture, based on a single stage vector quantizer and entropy coder.

The advantage of high-order entropy coding over the normally used first-order entropy coding has been revealed in Shannon's information theory. The high-order entropy of a source can be effectively exploited by using either the joint probability of (L + 1) symbols or the conditional probability of the current symbol with the knowledge of its L previous symbols (Lei *et al*., 1993).

In particular, the structure of vector quantizer used in (Kossentini *et al*., 1995) has been shown to be very successful in providing more accurate estimates of the

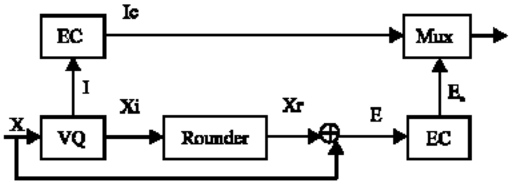

Fig.1: Proposed lossless CEC-VQ coder

statistical dependencies of the original signal while also reducing drastically the complexity of high order statistical modeling in multistage RVQ.

As shown in Fig. 1, we employ a CEC-VQ to quantize the input signal, where the output of VQ is then fed into a Entropy Coder (EC).The quantized signal is rounded to the nearest integer and the residual signal, form by subtracting the rounded quantized signal from the original one, is then coded using a entropy coder. Empirical work has shown that using higher order entropy coding does not lead to significant reduction in output entropy of the residual signal (Faouzi and Mark, 1995). Conventional distortion measures does not lead to minimization of the residual entropy, the overall system is lossless, its better to use the entropy of the residual signal as a distortion measure in the design of CEC-VQ. We used Entropy as measure of distortion.

The distortion measures used in the design of CEC-RVQ is, $d(x, y) = -\log_2 [pr (I (x-y))]$, where $I(\alpha)$ is the integer closest to the real $\alpha$ (Faouzi and Mark, 1995). VQ designed to minimize such a distortion measure also minimize the entropy of the residual signal.

The second idea is that only entropy is a measure of performance (Faouzi and Mark, 1995).

Figure 1 illustrates the encoding component consist of a single stage VQ, producing the output indices I. Associated with a fixed number of vector codebook. Initially, vector quantizer generates a codebook that have MSE distortion measure. This codebook has provided for next step of generation progression to minimize the entropy.

Our model based upon a single stage quantizer so it has reduced the complexity of entropy coder that construct by multiple stage in RVQ. Thus, the complexity and memory of the entropy coder grow exponentially with the number of conditioning symbols and the output alphabet sizes of the stage VQs (Kossentini *et al*., 1994).

## RESULTS

CEC-VQ was examined carefully in the context of image coding. Several images of size 512×512 were taken from the USC database to design the CEC-RVQ codebook.

Table 1: Results of measuring techniques

| Measuring techniques | Required result |
|---|---|
| MSE | 0 |
| SNR | Inf db |
| PSNR | Inf db |

Fig. 2a: Original Image

Fig. 2b: Reconstructed image

We implemented an image codec where 4×4 blocks of residuals are used as vector. For this, we used a set of 4 and 8, head and shoulder gray level images.

Table 1 shows the different objective measures calculated to prove the validity of our results. After compressing the input image and then decompressing the output image, the fidelity criteria were extracted using the MSE, SNR and PSNR.

Obviously, the values in the above table indicate a perfect reconstruction, as shown in Fig. 2b of the original image Fig. 2a.

Different images were tested successfully for their perfect reconstruction. Some of the images tested so far includes Ano, Aben, Barbara, Elaine, girl1, girll. Perhaps even more significant is the fact that improvement in bit rate can be achieved without the enormous storage and complexity requirements that accompany higher-order conditional EC-VQ, finite state VQ and other predictive

Table 2: Bit rate (bpp) of LENA (Compressed image ) using 4 and 8 training set of image

| | Code book size | | | | |
|---|---|---|---|---|---|
| Bit rate (bpp) | 256 k | 128 k | 64 k | 32 k | 16 k |
| 4 images T-set | 4.925 | 4.995 | 5.084 | 5.17 | 5.34 |
| 8 images T-set | 4.913 | 4.956 | 5.084 | 5.17 | 5.34 |

schemes of this type (Kossentini and Wilson, 1996). Experimental Resulted Bit rate validate it in this study.

Table 2 shows the reduced bit rate that was achieved after the compression of 8-bit gray scale images of Lena. In Table 2, we can clearly justify that in a training set of 8 or 4 images, the compression is exactly the same. It is only when the size of the codebook increases then a fractional difference is introduced.

The work proposed by Faouzi and Mark (1995) was further built upon thus leading to an entirely new framework. They used high order entropy; whereas we have introduced lossless compression using entropy constrained VQ. This method is more efficient and has a lower complexity as compared to the work done by the afore-mentioned authors.

## CONCLUSIONS

The goal of the present study was to obtain perfect reconstruction of an image. Here, the decompressed image should be a replica of the original. We have obtained 100% lossless image compression. Our system was tested on different images using codebooks of different sizes such as 256, 128, 64, 32 etc.

The codebook generation was a time consuming process. There is room for improvement in the sense that it could be made more efficient. This framework has experimented on 8-bit gray level images. Enhancements can be made for 16-bit and colored images.

In this study, we only consider 4 × 4 vectors; relatively large vector size provides an information theoretic benefit while still requiring manageable complexity and memory and the block sizes can be increased.

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