International Symposium on Signal Processing and its Applications, ISSPA, Gold Coast, Australia, 25-30 August, 1996.
Organized by the Signal Processing Research Centre, QUT, Brisbane, Australia.

SUBBAND CODING OF IMAGES USING PREDICTIVE VECTOR QUANTIZATION

*Kuldip K. Paliwal and Farshid Golchin**

School of Microelectronic Engineering, Griffith University
Brisbane, QLD 4111, Australia
K.Paliwal@me.gu.edu.au, F.Golchin@me.gu.edu.au

ABSTRACT

In this paper, two different schemes for predictive vector quantization (VQ) of subband decomposed images are investigated. The aim is to reduce the quantization error by incorporating memory into the VQ scheme. The first scheme is a form of finite-state VQ (FSVQ) which we will call subband FSVQ (SB-FSVQ) and the second is a form of predictive VQ (PVQ) applied to image subbands. We will refer to the second scheme as subband PVQ (SB-PVQ). It was found that both techniques outperform conventional subband VQ (memory-less) and spatial domain VQ in PSNR and perceptual terms. It was also found that despite SB-FSVQ's ability to capture non-linear dependencies, SB-PVQ performs slightly better.

1. INTRODUCTION

Vector quantization (VQ) has proven to be a powerful data compression technique [1] and has been applied successfully in many image coding applications [2]. Subband coding systems have also been used extensively in image compression for about a decade [3], [4]. Earlier systems relied solely on the use of scalar quantizers for quantizing the subband signals [3]. Since vector quantizers outperform scalar quantizers at a given bit rate, it would also make sense that they are utilised to quantize the subband signals. Westerink et. al. proposed such a system [4]. They decompose the image into 16 uniform subbands using 2-dimensional QMF filters. Samples at equivalent locations in the subbands are used to form 16-dimensional vectors which are then quantized using conventional (memory-less) VQ. Westerink et. al. exploited the correlation between the subbands, but neglected the correlations within each subband. In this paper, we exploit both inter-band (between the subbands) and intra-band (within each subband) correlations by incorporating memory into the subband VQ system.

2. INCORPORATING MEMORY INTO SUBBAND VQ

One solution for exploiting intra-band correlations would be to increase the size of our vectors. However since the complexity of a VQ scheme increases exponentially with its dimensions the resulting systems soon become unfeasible. A more reasonable solution is found in keeping the vector dimensions small while incorporating memory into the VQ scheme. Two such methods are described in the following sections.

2.1. Subband Finite-State Vector Quantization (SB-FSVQ)

Memory is incorporated into VQ by exploiting inter-vector correlations. Finite-state VQ (FSVQ) [1] is a popular method of exploiting such correlations. In FSVQ, instead of a single VQ codebook, a number of smaller codebooks are used. Each of these codebooks is associated with a particular state. The state of the encoder at any given time is determined using a next-state function which uses the previously encoded vectors as its input. In this fashion, we are able to use the past vectors to predict which codebook the next vector is going to belong to. Using a number of codebooks, one may reduce the distortion and/or the bit-rate of the VQ system.

In our encoder, we perform a uniform 16-band decomposition and form inter-band vectors (from subband samples at the same location). We also define a region of support for the next-state function as shown in Fig. 1. **A**, **B**, **C** and **D** are all 16-dimensional vectors. These vectors are used by the next-state function to determine the present state. The components of **A**, **B**, **C** and **D** grouped together form a 64-dimensional vector **S**. We proceed to quantize **S** using a VQ scheme with n codevectors where each codevector corresponds to a distinct state of our encoder. Once the state has been determined the subband vector is quantized using the vector codebook associated with that particular state.

A	B	C
D	**Next to Encode**	

Fig. 1. Previously encoded vectors **A**, **B**, **C** and **D**

* F. Golchin is supported in part by a CSIRO Division of Radiophysics postgraduate scholarship.

The design of the next-state function and the state codebooks is done in an open-loop fashion. A training set of 12 monochrome 512x512 pixel images is used. The training images are decomposed into subbands and the resulting subband vectors ware used to design the next-state function for a 32-state FSVQ. The next-state function is then used to classify the training vectors into a number of training pools (one for each state). The vectors in the training pools are used to design a codebook for each state. All state codebooks are designed to be of the same size.

2.2. Subband Predictive Vector Quantization (SB-PVQ)

Another popular method of exploiting inter-vector correlations is the predictive VQ (PVQ) [3]. In this scheme previously encoded vectors are used to predict the next vector and then a residual (prediction error vector) is quantized by VQ. Using linear prediction the linear correlations amongst the neighbouring vectors can be removed. It is worth noting that unlike PVQ, depending on how it was designed, an FSVQ system is able to exploit some non-linear dependencies that exist among neighbouring vectors.

In this scheme, we form our subband vectors in an identical fashion to the previous section. An optimal linear predictor (LP) is designed for each subband. The LP's are used to predict each component of the present vector from corresponding components in its neighbouring vectors (as in Fig. 1). The prediction is then subtracted from the current vector to calculate the residual vector which is quantized through VQ.

The residual codebook is designed based on the same training set as before. The images are subband decomposed and the LP coefficients for each subband of each image are calculated. The linear predictors are used to obtain the residual vectors which are pooled together. The vector codebook is then designed using the training residual vectors. We should also mention that in this scheme the LP coefficients for each subband must be sent along as side information but the increase in the overall bit-rate is almost negligible (~ 0.004 bpp).

3. SIMULATION RESULTS

Both schemes were tested using the Lena image (512x512 pixels, monochrome) which was outside the training set. The results are plotted in Fig. 2. Results for memory-less subband VQ and spatial domain VQ (using 4x4 image blocks) are also provided for comparison. It is clear that SB-FSVQ and SB-PVQ considerably outperform the other two techniques.

SB-PVQ also outperforms SB-FSVQ despite the latter's ability to exploit non-linear dependencies amongst neighbouring vectors. This would suggest that there are no significant non-linear relationships among the neighbouring vectors and that SB-FSVQ is (as expected) not able to exploit linear correlations as well as SB-PVQ.

Unlike the spatial domain VQ, all subband schemes do not suffer greatly blocking effects, however at low bit rates SB-PVQ produced the most visually pleasing results. The use of a residual signal in this scheme results in a smoothing effect in the reconstructed image.

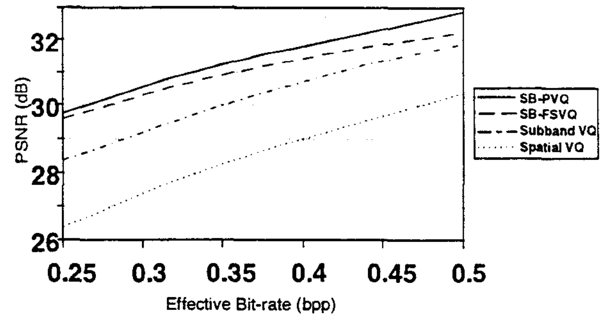

Fig. 2. Plot of PSNR vs. Bit-rate for the Lena image

4. CONCLUSION

In this paper two methods for predictive vector quantization were proposed and tested. The SB-PVQ system was found to outperform the SB-FSVQ system and two other conventional VQ based systems.

We were able to obtain images of reasonable quality (with PSNR > 30.72 dB) at bit-rates of around 0.313 bpp and higher. Although these results do not compare favourably with state-of-the-art schemes reported recently, they help to shed some light on possible uses of a powerful quantization technique such as VQ in conjunction with the subband decomposition.

An obvious improvement to these schemes would be to remove the constraint of having a fixed bit-rate over the entire image. This added degree of spatial adaptivity will almost certainly result in an improvement, but this improvement will be at the cost of introducing variable bit-rates and the added complexity of such systems.

REFERENCES

[1] A. Gersho and R.M. Gray, *Vector Quantization and Signal Compression*, Boston: Kluwer, 1992.

[2] N.M. Nasrabadi and R.A. King, "Image coding using vector quantization: A review," *IEEE Trans. Commun.*, vol. COM-36, pp. 957-971, Aug. 1988.

[3] J.W. Woods and S.D. O'Neil, "Subband coding of images," *IEEE Trans. Acoust. Speech and Signal Processing*, vol. ASSP-34, pp. 1278-1288, Oct. 1986.

[4] P.H. Westerink, D.E. Boekee, J. Biemond and J.W. Woods, "Subband coding of images using vector quantization," *IEEE Trans. Commun.*, vol. COM-36, pp. 713-719, June 1988.