

1-1-1995

## Hybrid predictive/VQ lossless image coding

P O. Ogunbona

*University of Wollongong*, philipo@uow.edu.au

Jianli Wang

*University of Wollongong*, jianli@uow.edu.au

Golshah Naghdy

*University of Wollongong*, golshah@uow.edu.au

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### Recommended Citation

Ogunbona, P O.; Wang, Jianli; and Naghdy, Golshah: Hybrid predictive/VQ lossless image coding 1995, 441-442.

<https://ro.uow.edu.au/infopapers/2154>

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### Abstract

A multiplicative autoregressive model is used in a lossless predictive image coding scheme. The use of vector quantisation (VQ) for compression of the model coefficients leads to an improved compression ratio. Both image adaptive and universal codebooks are considered. A comparative analysis of the new coder is presented through simulation results.

### Keywords

lossless, predictive, image, coding, vq, hybrid

### Disciplines

Physical Sciences and Mathematics

### Publication Details

Ogunbona, P. O., Wang, J. & Naghdy, G. (1995). Hybrid predictive/VQ lossless image coding. *Electronics Letters*, 31 (6), 441-442.

different word lengths is shown in Table 3.

**Table 3:** Total number of area units

Word length	Third	Sixth	Gain
8	102+24=126	28+48=76	40%
10	102+30=132	28+60=88	33%
12	102+36=138	28+72=100	28%

Some tradeoffs can also be done in the machine cycle count. If the timing is critical, it is preferable to use several small architectures that can easily be pipelined over the time. In general, in a third-order section as shown in Fig. 2, the number of cycles needed are the internal word length plus twice the coefficient length. However, if some of the coefficients are trivial, a significant reduction of the number of cycles is reached. For instance, in the sixth-order filter section shown in Fig. 4, the number of cycles needed per sample is only the internal word length plus the coefficient length. Accordingly, the two different filters need the number of cycles shown in Table 4. In terms of frequency it gives 82.2 MHz cycle frequency instead of 156.6MHz in the 12-bit case, which is, of course, a more convenient frequency to work with.

**Table 4:** Number of cycles

Word length	Third	Sixth	Gain
8	8+2x6=20	8+1=9	55%
10	10+2x6=22	10+1=11	50%
12	12+2x6=24	12+1=13	46%

**Conclusion:** The custom method will give several advantages when designing filters compared to standard digital signal processing methods. In this Letter it is shown that there are new parameters that can be traded-off with the filter order. We can accept an increased order if the gain is trivial or has simple coefficients. The gain is twofold: silicon area is saved and the algorithm can be more efficiently pipelined.

**Acknowledgment:** This work is supported by the Swedish National Board for Technical Development under contract 90-01252P.

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30 November 1994

Electronics Letters Online No: 19950255

P. Nilsson and M. Torkelson (Department of Applied Electronics, University of Lund, Box 118, 22100 Lund, Sweden)

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## Hybrid predictive/VQ lossless image coding

P.O. Ogunbona, J. Wang and G. Naghdly

*Indexing terms:* Image coding, Vector quantisation

A multiplicative autoregressive model is used in a lossless predictive image coding scheme. The use of vector quantisation (VQ) for compression of the model coefficients leads to an improved compression ratio. Both image adaptive and universal codebooks are considered. A comparative analysis of the new coder is presented through simulation results.

**Introduction:** Recent research interest in lossless image compression has been motivated by need in such diverse application areas as medical picture archiving and communications systems (PACS) and telemedicine. Lossy image coding schemes such as transform and subband coding, although well developed and capable of achieving high compression ratios, are not deemed suitable for medical applications because of the possible loss of important minute details in the reconstructed image. Reviews of several lossless coding schemes have appeared in the literature [1, 2]. The class of predictive lossless schemes have shown great promise [3]. A hierarchical decorrelation method based on interpolation (HINT) is also known to be very effective [2].

The success of predictive schemes is largely dependent on the degree of correlation present in image data, and various models have been proposed to exploit this redundancy [4, 5]. This Letter presents a new hybrid lossless image coding scheme based on the multiplicative autoregressive (MAR) model [6] and vector quantisation (VQ).

**Predictive multiplicative autoregressive image coding:** In the lossless coding scheme based on the two-dimensional multiplicative autoregressive (MAR) model, the image is first partitioned into blocks. The block size is chosen so that the assumption of stationarity holds over the pixels in the block; block sizes of 16x16 and 32x32 were used in [5]. For each block, the coefficients of the MAR model are estimated using the mean-removed pixel values in a recursive-least-squares scheme. Prediction of pixels using the estimated coefficients over a specified region of support (e.g. 3x3 NSHP) is then performed. The predicted value is rounded and the integer-valued prediction error (residuals) is calculated. More details are given in [5].

The encoder transmits (or stores), the entropy-coded residuals, the mean and the estimated model coefficients of each block. At the decoder, this information is used to reconstruct the image. In [5] it is shown that, by constraining the magnitude of the estimated coefficients to values less than unity, a stable model is obtained. It is noteworthy that the estimated model coefficients are scalar quantised.

A point that may have been overlooked in [5] is the possible correlation among the image blocks. In most natural images this correlation does exist. The proposed method exploits this correlation to achieve an improved performance over the basic MAR image encoder: the model coefficients are vector quantised. In [5] the use of a fixed predictor was also studied and some deterioration of performance was reported.

**Vector quantisation:** It is known from Shannon's rate distortion theory that by coding vectors rather than scalars, better performance is achievable [6]. Vector quantisation is able to exploit four interrelated properties of vector parameters [7]: linear dependency or correlation, nonlinear dependency, shape of the probability density function and dimensionality of the vector. Scalar quantisers do not exploit all these properties.

A VQ encoder consists of a codebook generated from a sequence of training vectors. In use, each vector to be encoded is compared with the codevectors in the codebook and the index of the closest (in the minimum squared error sense) codevector is transmitted (or stored) instead of the vector.

**Hybrid predictive/VQ lossless coding:** The proposed scheme proceeds as in the basic MAR lossless encoder [5], but goes further to exploit the inherent interblock correlation among the image blocks. The model coefficients of correlated blocks lie within a close range of each other. We have found very little difference in the prediction errors generated when the model coefficients in correlated blocks of the image are swapped.

Rather than use scalar quantisation for each model coefficient, VQ is used. There are two ways of generating the required codebook: (i) the set of model coefficients estimated from an image is used to produce an image adaptive codebook; (ii) the set of model coefficients from a set of training images is used to generate a universal codebook. In general the size of the codebook is less than the total number of image blocks. Simulation results using both types of codebook are presented.

The hybrid predictive/VQ encoder forms the predicted pixel value using the appropriate codevector in the codebook. In the

adaptive codebook case, both the codebook and the appropriate indices for each block are transmitted (or stored). It should be noted that vector quantisation does not lead to a violation of the stability criterion of the model because the centroid of each cluster is the mean of the vectors in the cluster. This will always be within the stability bound given in [5].

**Experimental results:** The proposed method has been compared to HINT and the basic MAR methods. Table 1 summarises the bit rates obtained using five (5) test images digitised at  $256 \times 256$  pixels and 8 bit/pixel. The MAR encoder was simulated using a  $16 \times 16$  block size and a  $4 \times 4$  NSHP region of support. MAR/IAVQ (1) is the proposed method with a  $16 \times 16$  block size, a  $4 \times 4$  NSHP region of support and an image adaptive codebook size of 32 codevectors. MAR/IAVQ (2) is the proposed method with a  $16 \times 16$  block size, a  $4 \times 4$  NSHP region of support and an image adaptive codebook size of 16 codevectors. MAR/UVQ is based on a universal codebook trained on the images Lena and baboon. The results for MAR/UVQ are still impressive, given that the encoded images are out of the training set and the training set is small. The results shown in Table 1 indicate the effectiveness of the proposed method.

**Table 1:** Performance comparison of different lossless encoders

Images	Image entropies (including side information) in bits/pixel					
	DPCM	HINT	MAR	MAR/IAVQ (1)	MAR/IAVQ (2)	MAR/UVQ
Jet	4.00	3.64	3.79	3.51	3.50	3.84
Urban	4.79	4.74	4.77	4.53	4.50	4.78
Lax	5.99	5.92	5.91	5.63	5.61	5.86
Lena	4.79	4.75	4.70	4.43	4.42	—
Baboon	6.39	6.25	6.22	5.94	5.92	—

**Conclusion:** This Letter introduces a new hybrid predictive/VQ lossless image coding technique. The performance improvement obtained from the proposed scheme stems from the reduced bit expenditure required to transmit (or store) the coefficients. The method exploits the interblock correlation existing in a partitioned image. The idea of vector quantisation of the model coefficients should find general use in other lossless predictive image coding schemes.

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23 January 1995

Electronics Letters Online No: 19950339

P.O. Ogunbona, J. Wang and G. Naghdy (Department of Electrical and Computer Engineering, University of Wollongong, NSW Australia)

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## Image coder based on residue number system for progressive transmission

A. Tatsaki, T. Stouraitis and C. Goutis

Indexing terms: Image coding, Residue arithmetic

A computationally efficient algorithm for image compression and progressive transmission is presented. A prime-factor discrete cosine transform (DCT) is applied, where the coefficients are computed in three groups and are residue represented by a different bit allocation. A novel lattice vector quantiser is used for the quantisation of each group.

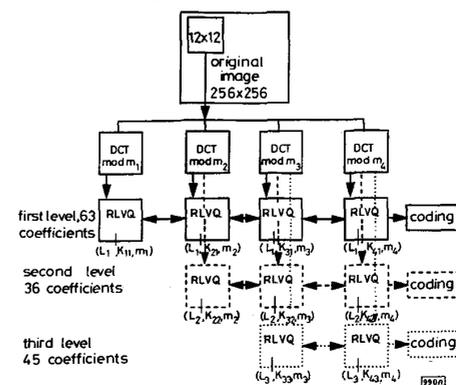
**Introduction:** Discrete cosine transformation combined with vector quantisation is considered as one of the most effective methods for image compression at 1 bit/pixel and below. A special class of vector quantisers (VQs) that are of particular interest due to their highly regular structure are the lattice quantisers (LVQs) [1, 2]. A lattice [1] is a regular arrangement of points in  $L$ -space that includes the origin or zero vector  $\mathbf{0}$ . The codebook of an LVQ is either a coset of a lattice or a truncated version of a lattice.

The residue number system (RNS) code results in modular, parallel and fault-tolerant architectures [3], and could solve some of the new problems brought on by advances in VLSI circuit technology.

In the proposed compression scheme, the DCT coefficients are computed independently in three groups and a new LVQ (RLVQ) is used for the vector quantisation of the residue vectors (RVs) of each group. The coding of each group represents a different level of the progressive image compression scheme. Four images are tested and progressively reconstructed at 0.2, 0.5 and 0.7 bit/pixel.

**Progressive image compression algorithm:** Progressive transmission of images on transform or spectral domain [4] has the advantage of information packing, and the image built up can be achieved adaptively based on the significance of the transform coefficients.

In the proposed algorithm, an image is divided into blocks of size  $12 \times 12$  and the DCT algorithm presented in [5] is applied. Only a few 3-point and 4-point 1-D DFTs, with some modifications, are required for the coefficients to be computed independently in three groups. The coefficients of each group are residue represented by a different moduli set. At the first level of the coder, for each block of pixels only the lower-frequency coefficients are computed and then are vector quantised by using the RLVQ algorithm. Then, a binary codeword index is assigned to each one lattice point. At the second and third level, the next low-frequency and high-frequency coefficients are computed and vector quantised, respectively. For the vector quantisation of each group, three lattices with different dimensionality and radius are used, because each group contains a different number of coefficients and the coefficients of each group are allocated with a different number of bits. The flow-graph of the proposed image coder is shown in Fig. 1.



**Fig. 1** Flow-graph of proposed image coder