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Shape VQ-based adaptive predictive lossless image coder

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Abstract

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Shape VQ-based Adaptive Predictive Lossless Image Coder

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ABSTRACT

A new shape adaptive predictive lossless image coder is proposed. Three classes of block shapes are delineated with associated "optimum" predictors. Each image is partitioned into sub-blocks that are classified into one of the three classes using vector quantisation. The encoder then employs the predictor corresponding to the class of the block under consideration. Performance evaluation of the proposed coder in comparison with four other lossless coders including lossless JPEG indicates its superiority.

1. INTRODUCTION

As telecommunications systems evolve towards a personal mobile environment, research in various applications that can take advantage of the ubiquity and freedom afforded by such systems is proceeding at a fast pace. With the promise held by a ubiquitous wireless system come several challenges related to the radio channel over which access into the existing fixed network will be made. Picture archiving and communication system (PACS) is an application that will benefit immensely from a mobile wireless communication network. Medical practitioners will be able to access medical image records from handheld terminals "anywhere anytime". The challenge posed to high data rate transmission required for efficient image communication via handheld terminals using the radio channel can be easily solved by efficient image coding methods. It must be borne in mind that for medical images, the coding method also needs to provide lossless or near lossless compression [1-4]. In a mobile environment there is also the problem of fading characteristics of the radio channel that leads to burst errors. It would be useful to design the image coder so as to be aware of the channel characteristics and thus mitigate the effect of channel errors. The subject of this paper is an attempt to solve the problem of image coding for efficient transmission over bandwidth limited channels; no attempt is made to combat channel errors.

Image coding methods suitable for medical images are essentially lossless in nature or near lossless. The most successful lossless image encoding schemes are based on some form of prediction; Differential pulse code modulation (DPCM) and its variants have been used extensively in the literature [1-3]. The various efforts to improve the performance of DPCM are geared towards designing efficient predictors or quantisers. The scheme described in this paper can be classified as an adaptive prediction based image coder. In a lossless predictive image coder, apart from the predicted values that need to be transmitted (or stored) the prediction error signal also needs to be transmitted. The non-stationary nature of image data makes it necessary to partition the data into sub-blocks that can be considered stationary before the application of the prediction scheme. However this strategy increases the side information that needs to be transmitted since information regarding each block needs to be known by the decoder for reconstruction.

The migration of telecommunications networks towards a wireless access paradigm for all services poses several challenges to such application as image and video databases. There is a need to efficiently access distributed image and video databases from hand-held low-resolution mobile terminals. An advantage of using a mobile terminal in accessing fixed telecommunication networks is the freedom given to the user to roam about and at the same time have access to required information. This brings about the concept of personal communication "anywhere anytime".

The rest of the paper is organised as follows. Section 2 describes the proposed lossless coder while Section 3 details the simulations conducted and the results. In Section 4 the implications of the results are discussed.

2. ADAPTIVE PREDICTIVE LOSSLESS IMAGE CODER

In this paper a shape adaptive DPCM in which the blocks of pixels are classified using vector quantisation (VQ) [5] is described. Each shape type is assigned an "optimum" predictor to effect a minimum error prediction. It is interesting to note that despite the improved performance obtained by using this scheme, there is no increase in side information required for reconstruction.

2.1. Shape Vector Quantisation

Each input image is divided into non-overlapping sub-blocks and the mean of each block is removed to reveal the shape. Using VQ each shape block is classified into one of three classes. The three classes are indicative of whether a block of pixels can be predicted using a fixed predictor or some adaptive predictor is required. There is a choice of an image adaptive or a universal VQ scheme in the classification stage. The advantage of using an image adaptive VQ derives from the possibility of reducing the distortion associated with the classification. However, the need to transmit the codebook as side information results in a constraint on the size of the codebook. This can negatively impact on the performance of the coder. In using a universal codebook (pre-trained on several images), the constraint of codebook length is removed but the ability of the codebook to adequately represent the input image may be reduced. Simulation was conducted to ascertain the extent of the impact of using a universal rather than an image-adaptive codebook. Table 1 shows the SNR (dB) of the reconstructed image *Lena* for various codebook sizes using both universal and image-adaptive codebooks.

Table 1: Signal-to-noise ratio of reconstructed image using different codebook sizes with universal and image-adaptive codebooks.

Codebook size	SNR (dB)	
	Universal codebook	Image-adaptive codebook
128	28.2	29.9
256	30.6	31.2
512	31.3	31.5

Similar trend in results has been observed with other test images. A compromise codebook size of 256 is chosen for the simulations reported in this paper. The block sizes range over 8x8, 16x16 and 32x32.

2.2. Adaptive Prediction and Lossless Coding

Three kinds of predictors are suggested for the classes arising from the vector quantisation classification:

(i) Fixed predictor in which each pixel is predicted from,

$$\hat{p}(i,j) = \frac{\rho * p(i,j-1) - \rho^2 * p(i-1,j-1) + \rho * p(i-1,j)}{\rho * (2-\rho)} \qquad (1)$$

In equation 1, the pixel value $p(i,j)$ is predicted from its north, northwest and west side neighbours. The constant ρ is assigned a value of 0.95. This predictor is hereafter referred to as fixed DPCM (F-DPCM).

(ii) Adaptive predictor in which the parameters are based on the shape of the block and determined using the 2-D Levinson algorithm. This predictor is hereafter referred to as adaptive DPCM (ADPCM).

(iii) Two-dimensional multiplicative autoregressive (MAR) [6] predictor. This predictor will subsequently be referred to as MAR.

To each of the block types in the codebook one of the three predictor types is assigned depending on which gave the minimum error. In other words the codebook index points to the appropriate predictor for blocks that map into the codebook block.

During the encoding phase, each input image is divided into non-overlapping blocks of pixels and the mean is removed. The resulting shape block is then classified using the generated codebook (image adaptive or universal) and the corresponding index is used to pick the appropriate predictor. The MAR predictor can be applied directly to the shape block with the mean and index of the block sent as side information; the other two predictors are applied to the actual pixels with the block index being sent as side information. Note that in all cases the prediction error signal is entropy encoded and transmitted along with the predicted values. The decoding algorithm is the inverse of the encoder.

3. SIMULATION RESULTS AND DISCUSSION

Several simulation were performed to test the performance of the proposed scheme and compare it to some other well known lossless coding techniques. The test images used include some medical images (*Skull, Abdo Thighs, Feet, Head* and *Pelvis*) digitized at 8 bits/pixel and of spatial resolution, 256x256 pixels. Other test images are *Lena, Baboon, Jet, Lax, Urban* and *Camera*. Figure 1shows some of the images used in the simulation.

3.1. Effect of block size on bit rate

The effect of block size used in the classification and subsequent coding is investigated and the results are shown in Table 2 for test images *Lena, Baboon, Jet, Skull, Abdo* and *Thighs*.

Table 2: Effect of block size on bit rate.

Test Image	Bit rate at different block sizes		
	8x8	16x16	32x32
Lena	4.27	4.25	4.66
Baboon	5.78	5.71	5.98
Jet	3.41	3.37	3.67
Lax	5.50	5.41	5.79
Skull	2.45	2.44	2.89
Abdo	4.70	4.60	5.01
Thighs	3.58	3.55	3.79

For the block sizes tested, 16x16 appears to be the optimum size. A block size of 8x8 and less will incur so much overhead that the improvement gained in coding efficiency is quickly eroded. For example, an 8x8 block encoded by the ADPCM or F-DPCM requires 8 bits for the index; an overhead of (8/8x8)=0.125bits/pixel. If MAR were applied, extra 8 bits are required thus bringing the overhead to 0.25 bits/pixel. These figures should be contrasted with an overhead of 0.03 bits/pixel and 0.06 bits/pixel respectively required for a 16x16 block size. The use of a 32x32-block poses problem because of the non-stationary nature of image data. The image segments enclosed by this block size will in most cases not be "homogenous" and the predictors will suffer some degradation.

3.2. Comparison between the proposed lossless coder and other schemes

The performance of the proposed shape VQ-based adaptive predictive (SVQAP) lossless coder is compared to that of (i) a lossless coder using a fixed predictor (F-DPCM) only, (ii) a lossless coder using an adaptive predictor (ADPCM) only, (iii) a lossless coder using the multiplicative autoregressive (MAR) model-based predictor only and, (iv) a hybrid lossless coder (HYBRID) proposed in [7]. The results of the comparisons are given in Tables 3 and 4 for the test images.

Table 3: Performance comparison between the proposed lossless coder and four other methods. M-1 is F-DPCM, M-2 is ADPCM, M-3 is MAR, M-4 is HYBRID and M-5 is SVQAP.

Test Image	Bit rate (bits/pixel) for 5 prediction methods				
	M-1	M-2	M-3	M-4	M-5
Lena	4.71	4.61	4.70	4.42	**4.25**
Baboon	6.39	6.24	6.22	5.92	**5.71**
Jet	4.00	3.95	3.79	3.50	**3.37**
Lax	5.99	5.93	5.91	5.61	**5.41**
Urban	4.79	4.61	4.77	4.50	**4.34**
Camera	4.13	4.12	4.09	3.90	**3.81**

Table 4: Performance comparison between the proposed lossless coder and four other methods. M-1 is F-DPCM, M-2 is ADPCM, M-3 is MAR, M-4 is HYBRID and M-5 is SVQAP.

Test Image	Bit rate (bits/pixel) for 5 prediction methods				
	M-1	M-2	M-3	M-4	M-5
Skull	2.50	2.78	2.63	2.61	**2.44**
Abdo	5.00	4.93	4.82	4.71	**4.60**
Feet	2.25	2.55	2.48	2.35	**2.21**
Head	3.07	3.36	3.10	3.07	**2.63**
Pelvis	4.20	4.31	4.20	3.93	**3.71**
Thighs	3.86	3.91	3.85	3.67	**3.55**

The bit rate achieved by using the proposed coder (column M-5 and bold) on the test images clearly indicates its superior performance. It should be noted that test images have been chosen to cover a wide range (from simple to complex) in order to ensure a full testing of the new algorithm.

ADPCM (16x16-block size) incurs an overhead of 0.09 bits/pixel when its three parameters are encoded at 8 bits and the MAR predictor (16x16-block size) 4x4 NSHP region of support requires an overhead of 0.16 bits/pixel. The latter overhead is computed from four parameters and one mean (4x8+8)/(16x16). When these overheads are compared to the 0.06 bits/pixel computed for the proposed scheme in the worst case, the reason for its performance is easily explained. Another reason that can be adduced for the superiority of the proposed is the possibility of appropriately switching between models for different block shapes. The other methods only used one model for all block shapes. The use vector quantisation to classify the blocks and the determination of "optimum" predictors for each class is fundamental to the proposed scheme in that the bits wasted in side information by the other schemes are saved. The hybrid VQ/predictive compression scheme (M-4) of [7] was proposed as an improvement over MAR. The coefficients are vector quantised to group blocks of similar shapes together. However, this method shares the limitation of MAR by using one predictor.

The lossless version of the JPEG image compression standard has been compared to the proposed technique [8]. Table 5 shows the bit rate achievable with the medical images. These figures (minimum value in bold) should be compared to those of column M-5 in Tables 3 and 4. The proposed technique is seen to outperform the lossless JPEG standard for these images.

Table 5: Performance of lossless JPEG predictors on some medical images.

Test Image	Bit rate (bits/pixel) for 7 lossless JPEG predictors						
	JP1	JP2	JP3	JP4	JP5	JP6	JP7
Skull	3.34	3.28	3.73	**2.51**	2.65	2.56	2.86
Abdo	5.80	5.43	6.15	5.04	5.16	**4.93**	5.25
Feet	2.92	2.39	3.09	2.27	2.43	**2.23**	2.43
Head	3.55	3.35	3.84	3.09	3.00	**2.90**	3.01
Pelvis	5.02	4.52	5.32	4.23	4.32	**4.00**	4.36
Thighs	4.88	4.07	5.10	3.89	4.12	**3.63**	4.13

4. CONCLUSION

A new lossless image coding method has been proposed and its performance compared with a number of lossless image coding techniques. The results indicate a superior performance in favour of the new method.

These methods are geared towards the minimisation of the squared prediction error. It would be interesting to investigate the performance of predictors based on minimisation of the entropy of the prediction error signal. Furthermore, with the increasing need to make image data available over the wireless medium for mobile communication applications, channel-aware lossless coders should also be studied.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] C. H. Hsieh, P. C. Lu, and W. G. Liou, "Adaptive predictive image coding using local characteristics", IEE Proceedings, Vol. 136, Pt. I, No. 6, pp. 385-390, December 1989.

[2] G. R. Kuduvalli, and R. M. Rangayyan, "Performance analysis of reversible image compression techniques for high-resolution digital teleradiology", IEEE Transactions on Medical Imaging, Vol. 11, No. 3, pp. 430-445, September 1992.

[3] P. Roos, M. A. Viergever, M. C. A. Van Dijke, and J. H. Peters, "Reversible intraframe compression of medical images", IEEE Transactions on Medical Imaging, Vol. 7, No. 4, pp. 328-336, December 1988.

[4] A. K. Jain, "Fundamentals of digital image processing", Prentice-Hall, Inc., 1989.

[5] R. M. Grey, "Vector quantization", IEEE ASSP Mag., Vol. 1, No. 2, pp. 4-29, April 1984.

[6] S. Burgett, and M. Das, "Predictive image coding using multiresolution multiplicative autoregressive models", IEE Proceedings-I, Vol. 140, No. 2, April 1993.

[7] P. Ogunbona, J. Wang, and G. Naghdy, "Hybrid predictive/VQ lossless image coding", Electronic Letters, Vol. 31, No. 6, pp. 441-442, March 16, 1995.

[8] R. Aravind, G. L. Cash, D. L. Duttweiler, H. Hang, B. G. Haskell, and A. Puri, "Image and video coding standards", AT&T Technical Journal, Vol. 72, No. 1, pp. 67-89, January/February, 1993.

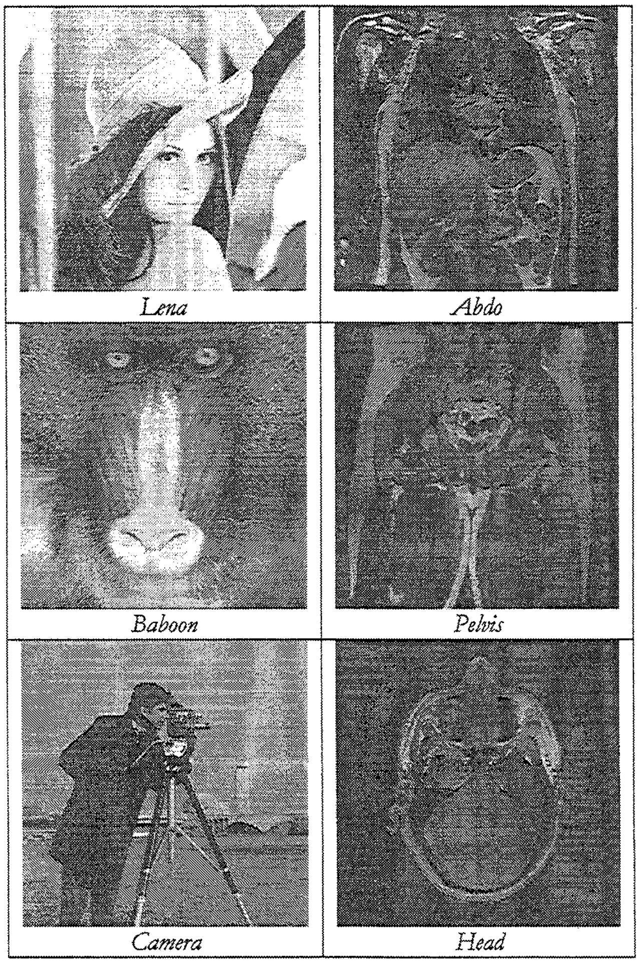

Figure 1: Some of the test images used in the simulations.