SIGNAL PROCESSING V: Theories and Applications
L. Torres, E. Masgrau, and M.A. Lagunas (eds.)

ON A HYBRID PREDICTIVE-INTERPOLATIVE SCHEME FOR REDUCING PROCESSING SPEED IN DPCM TV CODECS

RICARDO L. DE QUEIROZ
JOÃO B. T. YABU-UTI
Depto de Comunicações - Faculdade de Engenharia Elétrica
Universidade Estadual de Campinas
CP 6101 Campinas - SP 13081 BRAZIL
Fax : + 55-192-394717 Phone : + 55-192-397750

In this paper, DPCM was applied to Pyramid Coding strategy forming a simple and feasible hybrid extra/interpolative scheme. The Pyramid DPCM had the primary intention of increasing the interval between samples in DPCM. Furthermore, it has been shown that lower bit rates than regular DPCM are required for high quality resulting images.

1) INTRODUCTION

In DPCM TV CODEC's, the sampling rate lies near 10MHz, leaving an interval between samples in the order of 100ns and not allowing much time for all the needed processing. Due to the high degree of complexity of the CODEC's which have been lately proposed, their implementation could become a very difficult task. In the proposed scheme, adding parallel computation, this interval would increase to 200ns and 400ns, maintaining quality and reducing bit-rate. It also allows frequency differenciated coding, like Sub-Band Coding [1], multiresolution, progressive transmission as well as DPCM simplicity. Due to this fact, we do not expect great savings, but considerable performance improvement when compared with regular DPCM under the same conditions. That led us to a comparative behavior throughout this paper.

2) PYRAMID DPCM

The pyramid technique for progressive coding of images can be found in [2] and [3]. Let the original image be an array of NxN pixels (with N an integer power of 2) represented by ordering its lines in the sequence x(n). Let the sequence x'(n) be obtained by prefiltering and decimating x(n), with further interpolation of the decimated signal. Here, it is considered a 2-to-1 decimation and band restriction factor. In the pyramid construction process, we have made use of the following notation :

$x_0(n) = x(n)$

$x_{k+1}(n) = x_k(n)$ decimated

$x'_{k+1}(n) \Rightarrow x_k(n)$ by interpolation

$$L_k(n) = x_k(n) - x'_k(n) \qquad k=0,1,\ldots,M-1. \qquad \text{(E1)}$$

To recover x(n) we only need to reverse (E1) with the knowledge of

$$x_M(n)=L_M(n);\ L_0(n);L_1(n);\ldots;L_{M-1}(n)$$

In this Pyramid, there is an overhead of recorded nodes [3], which amounts roughly to doubling the number of original image pixels. However, if we had made use of a Reduced-Pyramid [3], these numbers would be equal. This pyramid scheme could be achieved without prefiltering before decimating. With proper interpolative filtering, half the samples in x'(n) would be coincident with those in x(n) and, therefore, the difference between them does not need to be coded.

In order to make the Pyramid feasible, we will restrict our attention to 3-level Reduced-Pyramid (M=2). Note that $L_2(n)$ and $L_1(n)$ would contain 1/4 of the nodes and $L_0(n)$ 1/2 of them. L_2 is also composed by 1/4 of the original samples of x(n). If we code L_2 with DPCM, its samples would be coded by taking the differences between the samples and extrapolative predictions of them [1]. Since L_1 and L_0 are formed by differences between interpolator's output and original samples, the whole system could be viewed as a hybrid inter/extrapolative prediction scheme for DPCM (or predictive/interpolative). The keypoint in this approach is the reduction of entropy of these differences due to the improved performance of interpolative prediction when compared with extrapolative one. Furthermore L_2's DPCM will work with a 4 times longer sampling interval.

In Figure 1 the steps towards the DPCM pyramid are pursued, as follows :

i) Decimate, by 2 and 4, x(n) in order to find $x_1(n)$ e $x_2(n)$.

ii) Code $x_2(n)$ with a regular DPCM, therefore $L_2(n)$ is formed by the differences between $x_2(n)$ samples and their predictions.

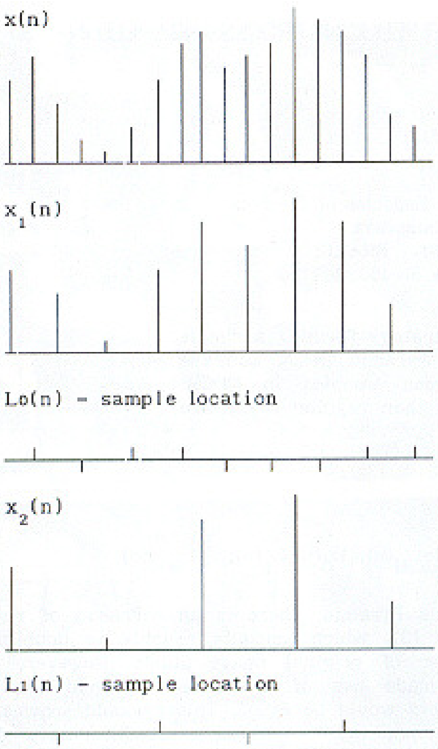
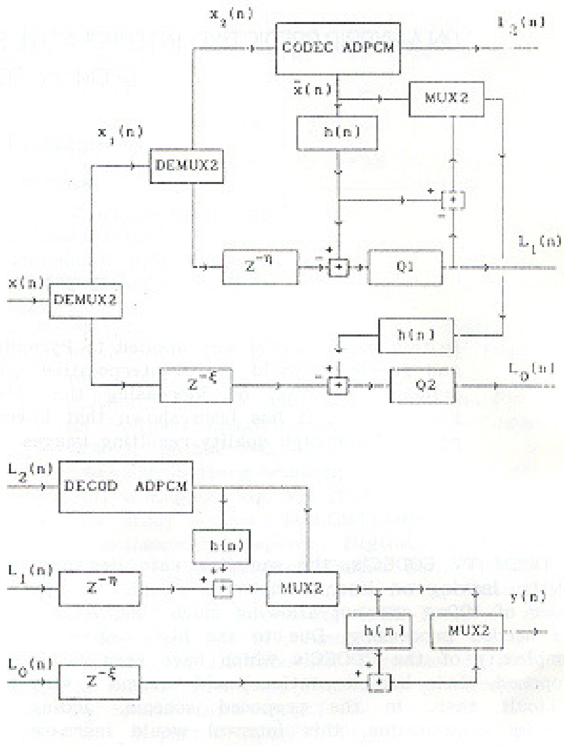


FIGURE 1 - EXAMPLE.



FIGÚRE 2 - PYRAMID DPCM TRANSMITTER AND RECEIVER

iii) Interpolate x_1(n) and let Lo(n) be formed by the errors of this interpolation and x(n). Do not code the errors corresponding to samples represented in x_1(n).

iv) Interpolate x_2(n) and let L1(n) be formed by the errors of this interpolation and x_1(n). Do not code the errors corresponding to samples represented in x_2(n).

In Figure 2, the Pyramid DPCM structure is presented. Note that, in DPCM CODEC, locally decoded values of its input [1] are used. Note, also, that this strategy is also applied to the construction of lower levels. In this figure, the filters are the interpolators and DEMUX2 and MUX2 are devices that divide and reconstruct, respectively, their input samples (even-n samples for one branch and odd-n for the other).

Being α, β, γ the mean bit rates for L2's DPCM, L1, Lo, the global bit rate produced by the Pyramid DPCM is given by :

$$R = (\alpha + \beta + 2\gamma) \frac{1}{4} \qquad \text{(E2)}$$

3) EXTRA/INTERPOLATIVE PREDICTORS

Let $\hat{x}(n)$ be the predicted value of x(n) in DPCM. With $\mathbb{A}$ and $\mathbb{X}$ as filter and input vectors, we have:

$$\hat{x}(n) = \mathbb{A}^t \, \mathbb{X} \qquad \text{(E3)}$$

$\mathbb{X}^t$=[x(n-1)] ; $\mathbb{A}$=[1] ;

$\mathbb{X}^t$=[x(n-1) x(n-1-L) x(n-L)] ; $\mathbb{A}$=[1 -0.7 0.7] ;

$\mathbb{X}^t$=as in [4] ; $\mathbb{A}$=[1 -1/2 1/2 -1/2 1/2] ;

$\mathbb{X}^t$=[x(n-1) x(n-2) x(n-3)] ; $\mathbb{A}$= FLS adaptive ;

Where L is the sample length of one line in a field and these sets $\mathbb{X}$-$\mathbb{A}$ represent Past Sample, Intrafield, Interfield [4], and FLS adaptive [5] prediction approaches, respectively.

The interpolator here used is a discrete extension of the Cubic Convolution Kernel [6] [7] due to its extreme simplicity (even considering its 7 coefficients), adequated polyphase structure [8] and good performance. According to the sampling rate of an upper level, we have a FIR filter interpolator given by its impulse response as

$h(0)=1 \quad h(\pm2)=0 \quad h(\pm1)=9/16 \quad h(\pm3)=-1/16$

$$x_{k-1}(2n+1) = (x_k(n)+x_k(n+1))\frac{9}{16} - (x_k(n-1)+x_k(n+2))\frac{1}{16} + L_{k-1}(n) \quad \text{(E4)}$$

for k=1 and 2, n=0,1...,N/2^k (into one line).

4) REGULAR x PYRAMID DPCM

By comparing the standard DPCM with the Pyramid DPCM, we may say that the main advantages of the later are :

a)Better data compression, due to (i) the prediction gain of interpolation over extrapolation and (ii) to the fact that is possible to adopt three distinct quantization procedures, one for each level, optimizing coding and achieving improved subjective performance in comparison to the regular scheme.

b)Enlargement of processing interval between samples. Those intervals are 4 times longer in L_2 and L_1 and 2 times longer for L_0. (See Figure 1).

c)Facility to extend to a Multiresolution approach by conditional progressive transmission

The main disadvantages rise from the needs for apropriated logic to multiplex those levels and for the addiction of parallel computation to conventional DPCM. For comparisons, in a first step we evaluated the error entropies. Let p(k) be the probability of X=k ($k \in K$); the entropies, here considered, are given by :

$$H[X] = -\sum_{i \in K} p(i) \log_2 p(i) \quad \text{(E5)}$$

$$H0 = H[x(n)] \quad \text{(E6a)}$$

$$H1 = H[x(n)-x(n-1)] \quad \text{(E6b)}$$

$$H4 = H[x(n)-x(n-4)] \quad \text{(E6c)}$$

$$H_{L1} = H[L_1(n)] \quad \text{(E6d)}$$

$$H_{L0} = H[L_0(n)] \quad \text{(E6e)}$$

Now, in order to compare the full-image and L_2 DPCM coding for past-sample prediction, we must compare H1 and H4. However, the entropy gain (G) must also take into account H_{L0} and H_{L1}. In table I, the results of tests over 3 images are presented leading to a mean gain around 0.2 b/pel. If prefiltering is permitted, as in TABLE II, the mean gain rises to 0.5 b/pel. This prefiltering will improve interpolation, eliminating aliasing, but it will slightly corrupt the samples in L_2.

$$G = H1 - \frac{H4+H_{L1}+2H_{L0}}{4} \quad \text{(E7)}$$

The prefilter used was an optimal [9] 15-tap FIR filter. Similar results were found with a 23-tap Hanning-weighted FIR filter. Repeating the process for Intrafield, Interfield and Intraline FLS-adaptive prediction approaches, it was verified that the mean gain decays with predictor's improvement. From 0.4 b/pel (Intrafield) to 0.2 b/pel (Interfield and FLS) with prefiltered inputs. However, with unfiltered inputs, the mean gain decays from 0.15 (Intrafield) b/pel to 0.07 b/pel (Interfield).

For coding simulations, we used exactly the same DPCM for L_2 and for the full-image. This includes adaptive two-dimensional prediction and fixed 31 level scalar quantizer. For the prediction equations we used intrafield prediction updated by a 2D LMS algorithm [10] with $\mu=0.1/255^2$.

$$A(n+1) = A(n) + \mu\,(x(n) - \hat{x}(n))\,X \quad \text{(E8)}$$

$L_0(n)$ was coded with a fixed 7- or 9-level quantizer, and L_1 with a 11-level fixed quantizer. Since we are invoking scalar quantization with Huffman coding, the lower bound for each quantizer mean bit rate is $1+\varepsilon$ b/pel. Figures 3-5 show comparative details extracted from reconstructed images. In these, the upper left quarter (UL) is extracted from original image; upper right (UR): (L_0:7 levels); Bottom Left (BL) : (L_0:9 levels); Bottom Right (BR): Standard DPCM. Those results are sumarized in TABLE III, indicating overall SNR and global mean bit-rate. In the comparative images, the high-quality reconstruction of images can be directly inferred, since the processed images are practically undistinguishable from the original, but Pyramid Coding required lower bit-rate.

5) CONCLUSION

We tried to propose Pyramid DPCM as an alternative to conventional DPCM in high sampling rate coding environments. One point that must be strongly enphasized is that the results here achieved are too far from optimum. They are relevant when compared with standard DPCM under the same conditions, situation into which Pyramid scheme reveals to be an attractive alternative combining Sub-Band, Pyramid and DPCM coding for achieving a superior performance.

	TABLE I						TABLE II			
IMAGE	H0	H1	H4	H_{L0}	H_{L1}	G	H4	H_{L0}	H_{L1}	G
BEACH	7.33	4.61	5.97	3.49	4.79	0.18	5.84	2.91	4.45	0.40
ZELDA	6.97	3.40	4.93	2.16	2.81	0.38	4.86	1.50	2.42	0.67
KITCH	6.86	3.56	4.90	2.59	3.56	0.15	4.78	1.98	3.19	0.42

FIGURES 3,4,5 - COMPARATIVE IMAGES

TABLE III:Bit-Rate(b/pel);SNR(dB)

IMAGE	UR PYR 1	BL PYR 2	BR DPCM
ZELDA	1.45/40	1.85/43	2.4/46
KITCH	1.8/45	2.2/49	2.5/54
BEACH	2.5/36	2.9/38	3.2/39

REFERENCES

[1] N.S.Jayant, P.Noll, *Digital Coding of Waveforms,* Englewood Cliffs, NJ, Prentice-Hall, 1984.

[2] P.J.Burt, E.H.Adelson, *The Laplacian Pyramid as Compact Image Code,* IEEE Trans Commun., COM-31, pp 532-540, April 1983.

[3] L.Wang,M.Goldberg,*Reduced- difference Pyramid,* Optical Engineering, Vol 28 #7, July 1989.

[4] CCIR Study Groups : Doc.CMTT/45E - July 1987.

[5] M.Bellanger, *Adaptive Digital Filters and Signal Analysis,* Marcel Dekker Inc., NY,1987.

[6] R.G.Keys, *Cubic Convolution Interpolation For Digital Image Processing,* IEEE Trans on ASSP, ASSP-29, pp 746-749, June 1983.

[7] R.L.Queiroz, J.B.Yabu-uti, *Técnicas de Projeto de Filtros FIR para Dizimação e Interpolação de Sinais Discretos,*RT-178, Contract 208/89, Tech. Report UNICAMP/ TELEBRÁS, July 1989.

[8] R.E.Crochiere, L.R.Rabiner, *Multirate Digital Signal Processing.* Englewood Cliffs, NJ, Prentice-Hall, 1983.

[9] H.S.Malvar, D.H.Stealin, *Optimal Pre- and Postfillters for Decimation and Interpolation of Random Signals,* IEEE Trans. on Comm., pp 67-73, January 1988.

[10] M.Hadhoud, D.Thomas, *Two-D Adaptive LMS Algorithm,* IEEE Trans.on Circuits and Systems, CAS-35, May 1988.