PSNR Improvement Using Different Prediction Coding In Image Compression.

Khamies Khalaf Hasan, Assistant Lecturer
Electrical Eng. Dept., University of Tikrit

Abstract

Differential Pulse Code Modulation (DPCM) is one of the predictive coding techniques. The number of previous pixels employed in the estimate operation is referred to as the order of the predictor. Predictor using one pixel for estimation is called "first order predictor". A "second order predictor" utilizes two pixels and an "*n*th order predictor" would employ *n* previous pixels.

From the results computed in this work, by testing the prediction mean square error (MSE) using different numbers of previous picture elements. The results show that the MSE decreases significantly by using up to three pixels, and further decreases of MSE are rather small by using more than three pixels that means the performance improvement becomes negligible and only a marginal gain beyond a third-order predictor can be achieved. That means, Peak Signal to Noise Ratio (PSNR) increases significantly by increasing the predictor order, the performance improvement becomes negligible beyond third order predictor.

Keywords: Peak Signal to Noise Ratio (PSNR), Predictor Order, MSE, DPCM.

تحسين نسبة الإشارة إلى الضوضاء باستخدام عمليات تخمين مختلفة في ضغط الصور

الخلاصة

تضمين الشفرة الرمزية التفاضلي (DPCM) أحد تقنياتِ التشفير التنبؤيةِ للحصول على إشارة الفرق أو الخطأ. إنَّ عددَ نقاطِ المكونة للصورة السابقةِ إذا أُستخدم في عمليةِ التخمينَ للصورةِ المسترجعة تحدد عندها درجة التخمين. إن استعمال نقطة واحدة من المكونات المكونة للصورة للتخمين يُدْعَى "مخمن أول ". أي "مخمن ثاني"يَستعملُ نقطتين سابقة من المكونات المكونة للصورة للتخمين و " مخمن nth" يَستخدمُ عدد n من نقاط سابقة من المكونات المكونة للصورة للتخمين. مِنْ النَّتائِجِ التي حَسبتْ في هذا العملِ، يَختبرُ خطأ التنبؤَ وذلك باستعمالُ أعدادَ مختلفةَ مِنْ عناصرِ الصورةِ السابقةِ. إي يَنْقصُ الخطأ بشكل ملحوظ باستخدامُ ثلاثة من نقاط سابقة من المكونات المكونة للصورة للتخمين. و باستعمال أكثر مِنْ ثلاثة من نقاط سابقة من المكونات المكونة للصورة للتخمين وجدنا بان تحسينَ الأداءَ يُصبحُ غير ملحوظ وهامشي ما بعد استخدام مخمن من الدرجة الثالثة. ذلك يَعْني، ان (نسبة ذروة الإشارة إلى الضوضاء) تزيدُ بشكل ملحوظ بزيَأْدة درجة المخمن،و يُصبحُ تحسينَ الأداءَ غير مؤثر ما بعد استخدام مخمن من الدرجة الثالثة.

الكلمات الدالة: ذروة نسبة الإشارة إلى الضوضاء ، درجة التخمين ، معدل مربع الخطأ للتنبؤ ، تضمين الشفرة الرمزية التفاضلي.

Notation

a's	prediction coefficient
BPP	Bit Per Pixel
CR	Compression Ratio
d_i	Quantizer decision level
d_q	Quantized difference
DCT	Discrete Cosine Transform
DFT	Discrete Fourier Transform
DM	Delta Modulation
DPCM	Differential Pulse Code Modulation
e_{RMS}	The root-mean-square error
e_q	Quantization error
FT	Fourier Transform
HVS	Human Visual System
JPEG	Joint Photographic Experts Group
L	Number of gray levels
LP	Linear Predictor
N*N	Squared image size in pixels
PSNR	Peak to peak Signal to Noise Ratio
SQ	Scalar Quantizer
SNR	Signal to Noise Ratio
S	Actual (present) sample value.
$\hat{S}$	Predicted sample value.
$\overset{\cdot}{S}$	The reconstructed sample value
VQ	Vector Quantization

Introduction

The basic idea behind (LP) linear prediction is that a sample of signal can be predicted as a linear combination of previous samples. By minimizing the sum of the squared differences between input samples and linearly predicted ones, a unique set of predictor coefficients can be determined [1,2]. The DPCM compression method is a member of the family of differential encoding compression method. It is based on the well-known fact that neighboring pixels in an image are correlated, so their differences are small. In predictive coding the difference signal between the actual sample and its predicted value is quantized and transmitted. This technique has been used in speech coding, image coding, and in biomedical field [3].

The main stages of DPCM system for still image can be illustrated in Fig.1. As shown in Fig.2, the predicted value of (S_o) denoted by $\hat{S}_o$ is given by:

$$\hat{S}_o = a_1 \overset{o}{S}1 + a_2 \overset{o}{S}2 + a_3 \overset{o}{S}3 + ... + a_n \overset{o}{S}n \dots\dots(1)$$

$$= \sum_{i=1}^{n} a_i \overset{o}{S}_i \dots\dots\dots\dots\dots\dots (2)$$

The difference signal is then:

$$d_\circ = S_O - \hat{S}_O \dots\dots\dots\dots\dots (3)$$

The difference will be quantized to d_q and transmitted. Where $\overset{o}{S}_1$, $\overset{o}{S}_2$, $\overset{o}{S}_3$ and $\overset{o}{S}_n$ are the reconstructed values of S_1, S_2, S_3 and S_n respectively. a_1, a_2, a_3 and a_n are called prediction weighting coefficients. The set of predictor coefficients may be fixed for all images (global prediction), or may vary from image to image (local prediction). The sum of the prediction coefficients in equation (1) normally is required to be less than or equal to one. This restriction is made to ensure that the predictor's output falls within the allowed range of gray levels. One of the possible predictors which provide satisfactory performance over wide range of actual images are given below:

$$\hat{S}_o = a_1 \overset{o}{S}_1 \dots\dots\dots\dots\dots\dots.(1\text{-}1a)$$

a_1 is normally chosen equal to 0.95"first order predictor".

$$\hat{S}_o = a_1 \overset{o}{S}1 + a_2 \overset{o}{S}2 \quad \ldots\ldots\ldots\ldots\ldots(1\text{-}1b)$$

The prediction coefficient a_1 and a_2 are chosen normally equal to 0.5"second order predictor" .

$$\hat{S}_o = a_1 \overset{o}{S}1 + a_2 \overset{o}{S}2 + a_3 \overset{o}{S}3 \ldots\ldots (1\text{-}1c)$$

The coefficient a_1 and a_2 are chosen equal to 0.75 and a_3 equal to -0.5"third order predictor". [4]

A scalar quantizer with 3-bit has been employed whose normalized levels distribution was given in table (1). The actual levels are calculated by multiplying the normalized levels by the standard deviation of input signal of the quantizer.

The decoder makes the same prediction, from previous decoded samples, to which the received difference signal is added to regenerate the present sample value, and so on.

Normally the dynamic range of the difference signal is much smaller than the dynamic range of input signal. Since the difference signal amplitude is modeled by Laplacian Density function, a nonuniform quantizer matched to the difference signal statistics is employed.

Quantization

Quantization is the process of approximation a continuous–amplitude signal by a discrete–amplitude signal, while minimizing a given distortion measure. Unlike sampling, quantization is an intrinsically lossy process, and after the quantization the original signal cannot be recovered without errors. In a quantized signal each sample can be represented by an index of a value selected from a finite set. The quantizer reduces the number of bits needed to store the image data by reducing the precision of those values. There are two types of Quantization; Scalar Quantization and Vector Quantization. In scalar quantization, each input symbol is treated separately in producing the output, while in Vector Quantization the input symbols are clubbed together in groups called vectors, and processed to give the output. This clubbing of data and treating them as a single unit increases the optimality of the vector quantizer, but at the cost of increased computational complexity; In the present work scalar quantization are applied [5,6].

Scalar Quantization (SQ)

Scalar quantization is the process of mapping one signal sample at a time. This type of quantization is the simplest, most popular and conceptually of great importance. Scalar quantization is an example of a lossy compression method, where it is easy to control the trade-off between compression ratio and the amount of loss. However, because it is so simple, its use is limited to cases where much loss can be tolerated. Scalar quantization can be used to compress images, but its performance is mediocre.

There are two types of quantizers: uniform and non-uniform quantizer. In the uniform quantizer the dynamic range of the signal is divided into equally spaced intervals where as in non-uniform quantizer the dynamic range is divided into unequally spaced intervals.

Uniform quantizers perform optimally for signal with uniform distribution. Non-uniform quantizer is specified for non-uniform distribution. It is more complex, but the added complexity is often worthwhile because it can be used to reduce the perceptual effects of the quantization. Nonuniform quantizers are typically attempt to produce digital signals with higher average SNR.

In the scalar quantization, the value of image pixel (f) is compared to a set of decision levels. If the pixel value (f) falls between two adjacent decision levels (d_i, d_{i+1}), it is quantized to a fixed reconstruction level (r_i) lying in the quantization band.

The quantization problem entails specification of a set of decision levels d_i and a set of reconstruction levels r_i such that if:

$$d_i \leq f < d_{i+1} \dots\dots\dots\dots (4)$$

Then the pixel value (f) is quantized to a reconstruction level r_i. Fig.3 illustrates the decision and reconstruction levels. Table (1) shows optimum quantizer parameters for Laplacian density [7, 8].

Results and Discussion

An important concept here is the idea of measuring the average information in an image, referred to as the Entropy. The Entropy for an N*N image can be calculated: [9]

$$Entropy = -\sum_{i=0}^{L-1} p_i \log_2 p_i \quad \dots(5)$$

Where P_i= the probability of the ith gray level = n_k/N^2

n_k = the total number of pixels with gray value k

L =the total number of gray level (e.g., 256 for 8 bit)

The images used have different information content as shown in Fig. 4. Subjectively one can easily recognize that image Trees is one of the lowest information since it contains almost smooth areas. The image Moon is one of moderate information contents because it contains some smooth areas and some texture, and the image Board has high information. To support this statement, the entropy of each image is calculated and listed in table (2).

The DPCM system with first, second and third order predictor has been employed to calculate the prediction difference signal of Board image. Pixels used for prediction and the values of prediction coefficients were chosen according to equations (1-1, a, b, c) and Fig.5. A 3-bit non-uniform quantizer with normalized level distribution given table (1) was used. The actual level distribution was obtained by multiplying the normalized level with the standard deviation of the difference signal. Fig.5 shows the prediction difference signal for *1st, 2 nd* and *3 rd* order predictor respectively. From the figure one can recognize that *3 rd* order predictor gives the smallest difference signal. PSNR listed in table (3) support this claim.

Conclusions

The philosophy underlying predictive coding is to use prediction to remove redundancy between inter pixels and encode only the new information.

In a general DPCM system, see figures (6,7 and8) a pixel's gray level is first predicted from the preceding reconstructed pixel's gray level values. The difference between the pixel's gray level value and the predicted value is then quantized. Finally, the quantized

difference is encoded and transmitted to the receiver.

From the results obtained, one can conclude the two basic conclusions:

1. The Peak Signal to Noise Ratio (PSNR) increases significantly by increasing the predictor order, the performance improvement becomes negligible beyond third order predictor.

2. The actual efficiency of the compression system depends to some extent on the original image quality.

References

1. Kim, J. H., "Lossless Wideband Audio Compression: Prediction and Transform", Technische Universit at Berlin, PhD Thesis,2003.Website: http://edocs.tuberlin.de/diss/2003/kim_jonghwa.pdf

2. Irie, K., Okumura, Y., Sakuria, N., and Kishimoto, R., "High-Quality Subband Coder for High Difinition Television Transmition (HDTV)", IEEE Trans. On Circuit and systems, Vol.4, pp. 195-199, 1994.

3. Nave, G., and Cohen, A., "ECG Compression using Long-Term Prediction", IEEE Trans. On Biomedical Engineering, Vol.40, pp.877-855, 1993.

4. Gonzalez, R. C., and Woods, R. E., "Digital Image Processing", Pearson Education Asia Pte Ltd., 2000.

5. Motta, G., " Optimization Methods For Data Compression", Brandeis University, PhD Thesis, 2002. Website: www.cs.brandeis.edu/~gim/Papers/optimizationMethodsForDataCompression.pdf

6. Rodríguez , L. S. "Fast Piecewise Linear Predictors for Lossless Compression of Hyperspectral Imagery", University of Puertorico, Mayaguez Campus, Master's thesis, 2003.Website:http://grad.uprm.edu/tesis/rodriguezdelrio.pdf

7. Pratt, W. K., "Digital Image Processing", John Wiley & Sons, 1978.

8. Thomas P. B., Kambiz N., Craig H. R.., " Speech Coding: A Computer Laboratory Textbook" , John Wiley and Sons Inc, 2001.

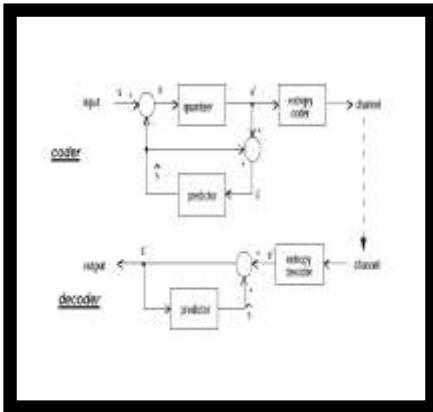9. Scott E. Umbaugh, "Computer Vision and Image Processing", Prentice Hall,998.

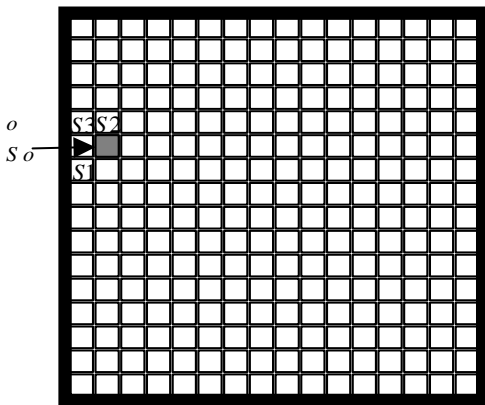**Fig .(1) :(DPCM) system.**   .

(a)

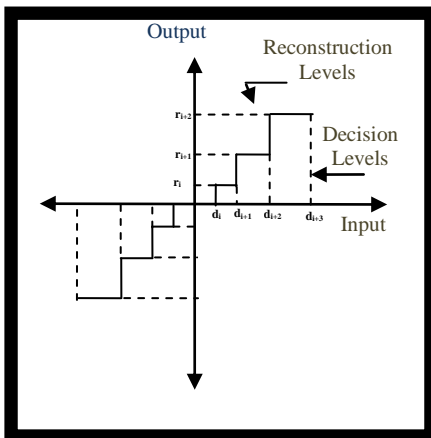**Fig. (2) :Location of pixels used for prediction of S_o in a digital image .**
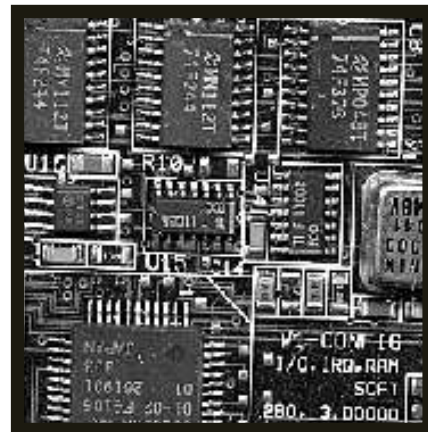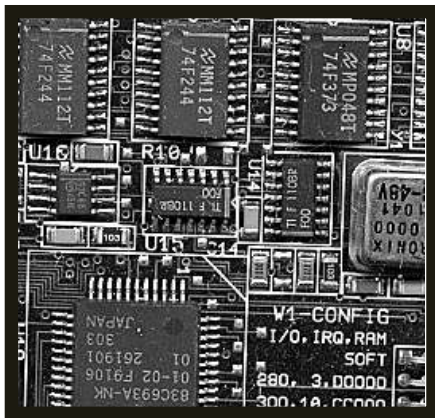

(b)

Fig .(3): Quantization decision and reconstruction levels.
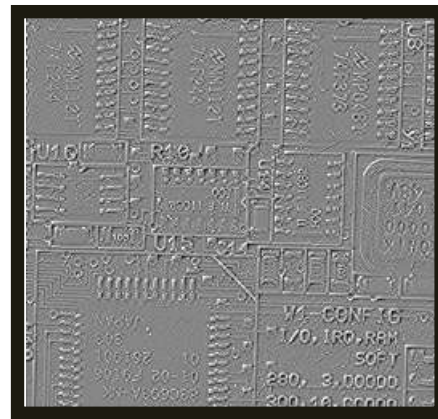

(c)

Fig .4: the different images used with different information contents :
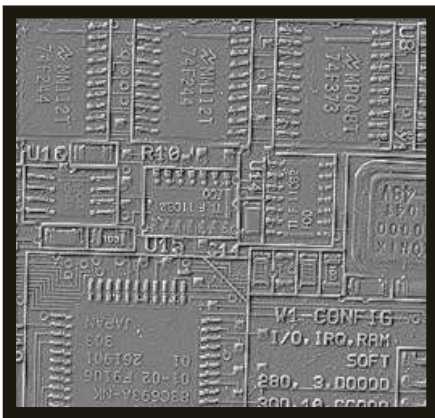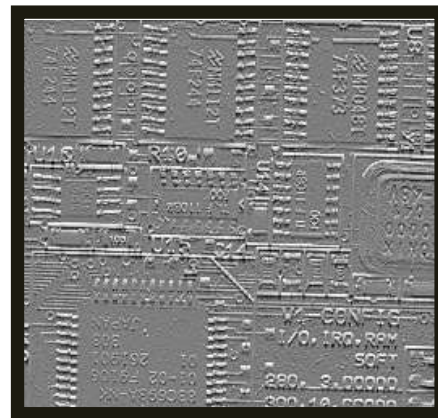a .Trees image.
b. Moon image.
c .Board image   .

a. (The original Board image 8bp)

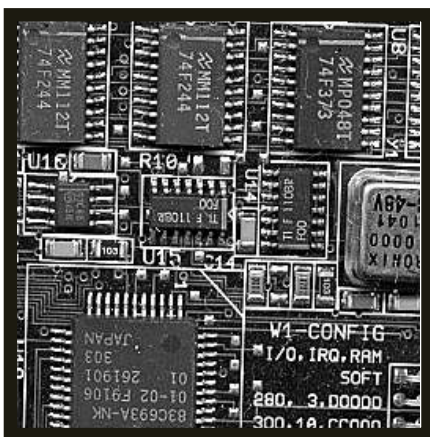**b .Prediction difference signal**
(using first order predictor). 3bpp

c .Prediction difference sign
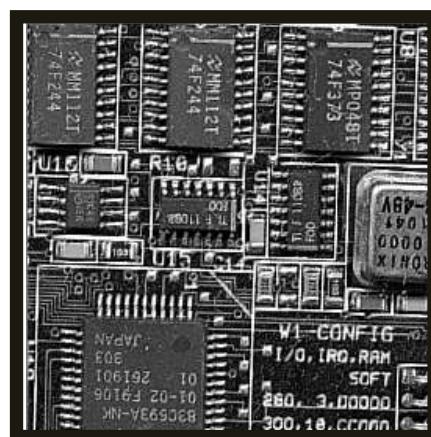**(using second order predictor).3bpp**

d .Prediction difference signal
(using third order predictor).3bpp

Fig .(5) :Board image using three types of predictor's difference images.

a)   Original image with 8bpp

b)Reconstructed image of the

Fig .(6): DPCM of Board image.

(a)

(a)

(b)

(b)

(c)

(c)

Fig.(7): DPCM of Trees image .
(a) Original image with 8bpp.
(b) Reconstructed image of
the optimum DPCM with 3bpp.
(c) Prediction difference signal.

Fig.(8) : DPCM of Moon image.
(a) Original image with 8bpp.
(b) Reconstructed image of
the optimum DPCM with 3bpp.
(c) Prediction difference signal.

Table (1):Laplace density signals for 1,2,3,4 and 5-bits optimum quantizer parameters [8].

1 bit		2 bit		3 bit		4bit		5 bit	
d_i	r_i	d_i	r_i	d_i	r_i	d_i	r_i	d_i	r_i
∞	0.707	1.102	0.395	0.504	0.222	0.266	0.126	0.147	0.072
		∞	1.810	1.818	0.785	0.566	0.407	0.302	0.222
				2.285	1.576	0.910	0.726	0.467	0.382
				∞	2.994	1.317	1.095	0.642	0.551
						1.821	1.540	0.829	0.732
						2.499	2.103	1.031	0.926
						3.605	2.895	1.250	1.136
						∞	4.316	1.490	1.365
								1.756	1.616
								2.055	1.896
								2.398	2.214
								2.804	2.583
								3.305	3.025
								3.978	3.586
								5.069	4.371
								∞	5.768

Table (2) : Information contents (entropy) of three gray scale images.

Image	information
Trees image	4.6240
Moon image	5.8807
Board image	6.5896

Table (3): PSNR improvements in Board image.

Predictor type	Bit per pixel (bpp)	PSNR (dB)
First order predictor	3 bpp	15.4595 dB
Second order predictor	3 bpp	17.3608 dB
Third order predictor	3 bpp	19.8808 dB