USCIPI REPORT 560

SEMIANNUAL TECHNICAL REPORT

Covering Research Activity During the Period
1 September 1974 through 28 February 1975

William K. Pratt
Project Director
(213) 746-2694

Image Processing Institute
University of Southern California
University Park
Los Angeles, California 90007

31 March 1975

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Air Force Eastern Test Range under Contract No. F08606-72-C-0008, ARPA Order No. 1706

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Image Processing Institute University of Southern California, University Park Los Angeles, California 90007	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

IMAGE PROCESSING RESEARCH

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Semiannual, 1 September 1974 to 28 February 1975

5. AUTHOR(S) *(First name, middle initial, last name)*

William K. Pratt (Project Director)

6. REPORT DATE 31 March 1975	7a. TOTAL NO. OF PAGES 166	7b. NO. OF REFS 47
8a. CONTRACT OR GRANT NO. F08606-72-C-0008	9a. ORIGINATOR'S REPORT NUMBER(S) USCIPI Report 560	
b. PROJECT NO. ARPA Order No. 1706 c. d.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

10. DISTRIBUTION STATEMENT

Approved for release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209

13. ABSTRACT

This technical report summarizes the image processing research activities performed by the University of Southern California during the period of 1 September 1974 to 28 February 1975 under Contract No. F08606-72-C-0008 with the Advanced Research Projects Agency, Information Processing Techniques Office.

The research program, entitled, "Image Processing Research," has as its primary purpose the analysis and development of techniques and systems for efficiently generating, processing, transmitting, and displaying visual images and two dimensional data arrays. Research is oriented toward digital processing and transmission systems. Five task areas are reported on: (1) Image Coding Projects: the investigation of digital bandwidth reduction coding methods; (2) Image Restoration and Enhancement Projects: the improvement of image fidelity and presentation format; (3) Image Data Extraction Projects: the recognition of objects within pictures and quantitative measurement of image features; (4) Image Analysis Projects: the development of quantitative measures of image quality and analytic representation; (5) Image Processing Support Projects: the development of image processing hardware and software support systems.

****

14. Key words: Image Processing, Digital Image Processing, Image Coding, Image Enhancement, Image Restoration, Image Processing Software, Image Processing Hardware, Color Image Processing.

DD FORM 1 NOV 65 1473

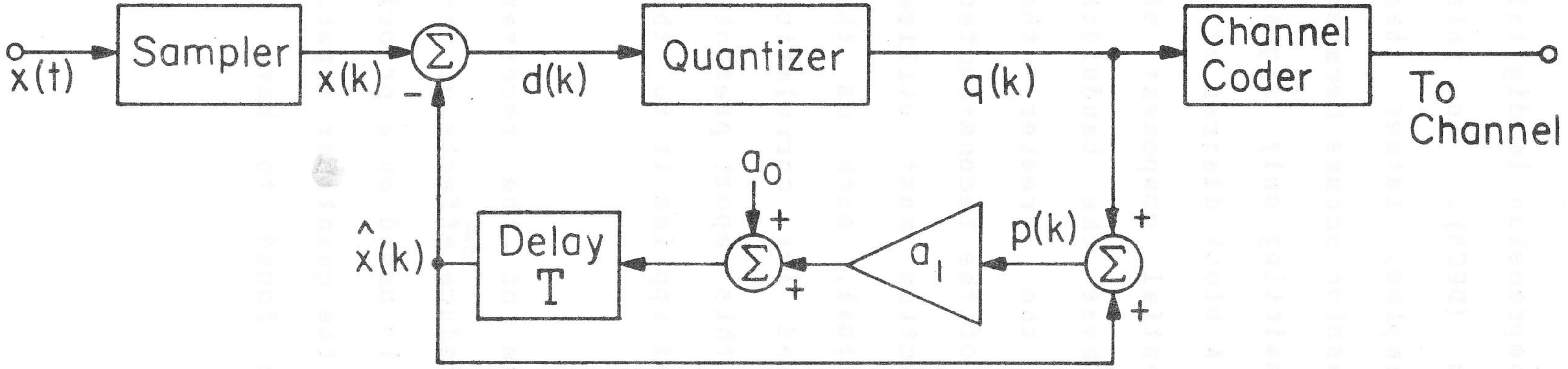
UNCLASSIFIED
Security Classification

3.2 Optimum Image Reconstruction from DPCM Samples

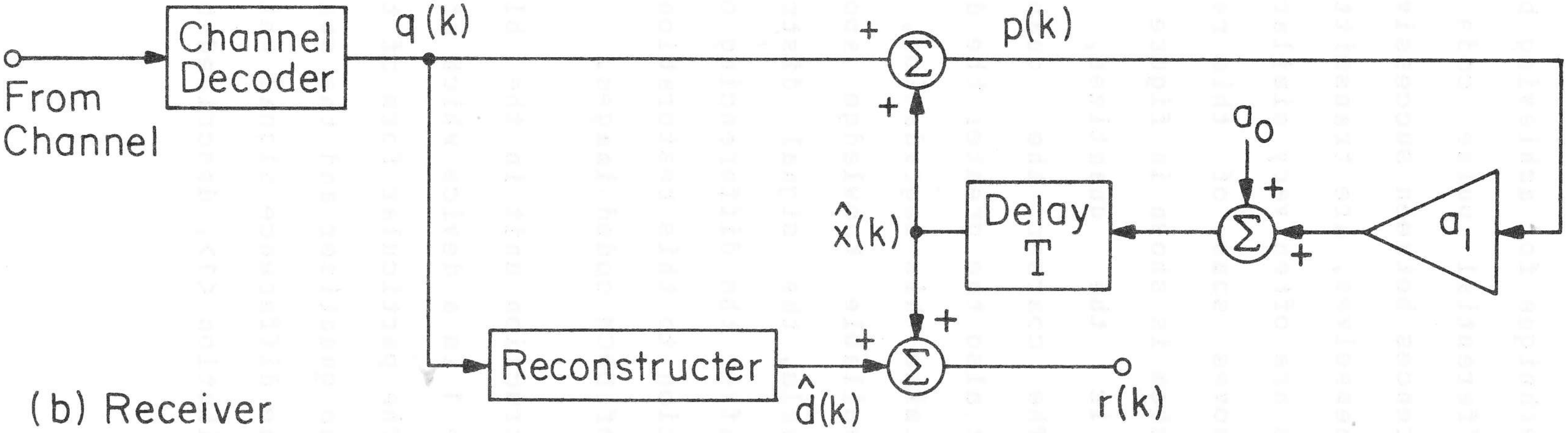
Michael Huhns

A common technique for achieving bandwidth compression in digital systems is differential pulse code modulation (DPCM). In this technique differences between successive signal samples, rather than the signals themselves, are transmitted. Compression occurs because adjacent samples are often very similar, and transmitting only signal differences removes some of this redundancy. A block diagram of a typical DPCM system is shown in figure 1. An essential component of this system is the quantizer, which achieves the bandwidth compression. The coarser the quantization, the greater the compression, but also the greater the degradation of the reconstructed signal. To minimize this degradation, a reconstruction must utilize all of the available knowledge about the signal, such as the quantization levels, the signal distribution, and any correlation which remains after the differencing operation. This report presents an optimal solution to this restoration problem and applies it to the reconstruction of DPCM coded images.

The reconstruction unit in the block diagram of the receiver shown in figure 1 is a device which attempts to reduce the effects of the quantization. The particular form of this device is based on a priori knowledge of the quantizer and the statistics of the quantizer input. This input is the difference signal which has been found to have a Laplacian distribution <1>, described by



(a) Transmitter



(b) Receiver

Figure 3.2-1. Spatial predictive DPCM coding system with quantization restoration

$$p(x) = \frac{1}{\sqrt{2\sigma}} \exp(-|x|/2\sigma) \tag{1}$$

The distribution of the difference signal for the "girl" image (see figure 4) is shown in figure 2. It can be seen that a Laplacian could model this distribution quite well. However it has been found that the difference signals are correlated, so that an accurate statistical representation of them must also account for this fact. Figure 3a shows the actual two-dimensional distribution of the DPCM coded "girl." For this image the average correlation for adjacent difference samples has been measured as 0.4. These samples can then be modeled by a correlated two-dimensional laplacian density, written as

$$p(x, y) = \frac{1}{2\sigma_x \sigma_y \sqrt{1-r^2}} \exp\left\{-\frac{1}{\sqrt{2(1-r^2)}}\left(\left|\frac{ax}{\sigma_x} - \frac{by}{\sigma_y}\right| + \left|\frac{ay}{\sigma_y} - \frac{bx}{\sigma_x}\right|\right)\right\} \tag{2}$$

where

$$\sigma_x^2 = E\{x^2\} \tag{3}$$

$$\sigma_y^2 = E\{y^2\} \tag{4}$$

$$r = \frac{E\{xy\}}{\sigma_x \sigma_y} \tag{5}$$

$$a = \sqrt{1+r} + \sqrt{1-r} \tag{6}$$

$$b = \sqrt{1+r} - \sqrt{1-r} \tag{7}$$

Figure 3b contains a plot of this density function for r=0.4 and $\sigma_x = \sigma_y$.

The two-dimensional Laplacian distribution is seen to provide an accurate model for the DPCM samples. These samples are quantized

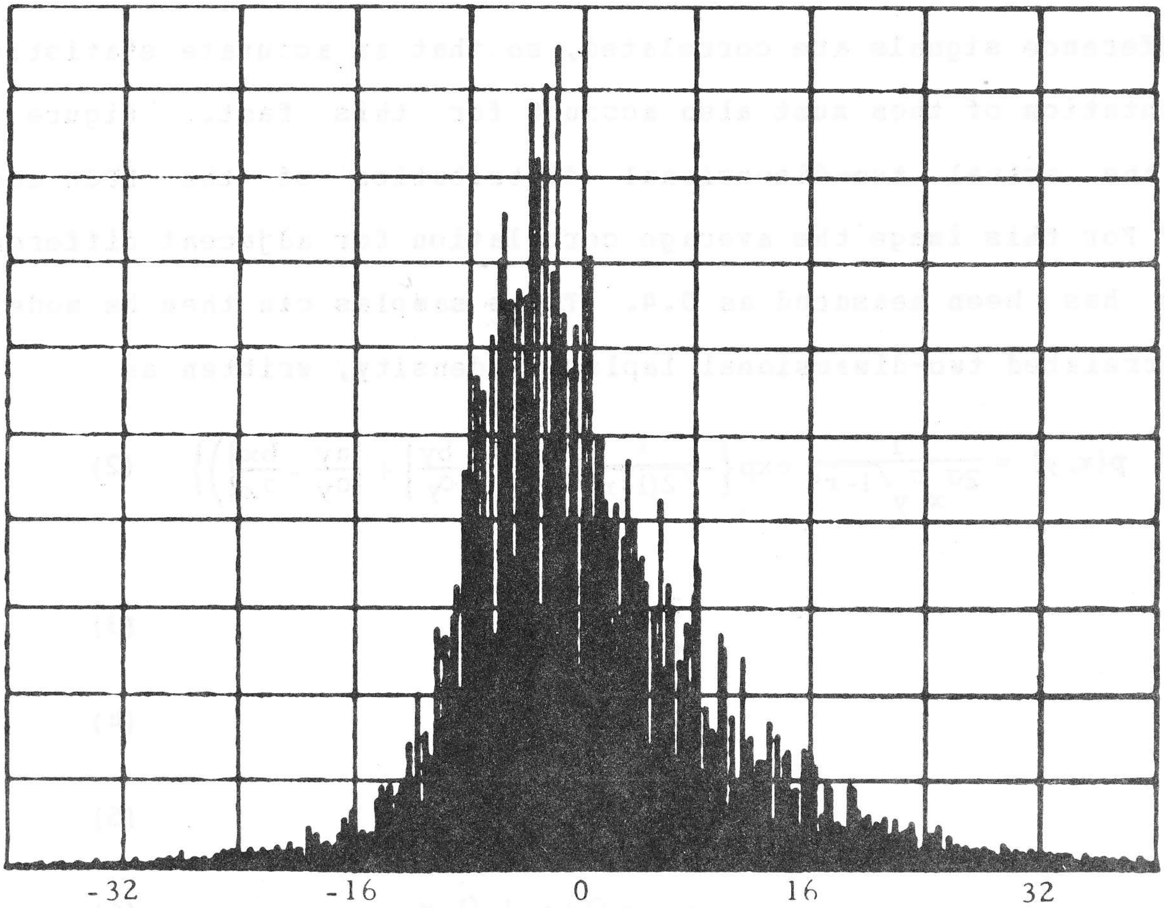
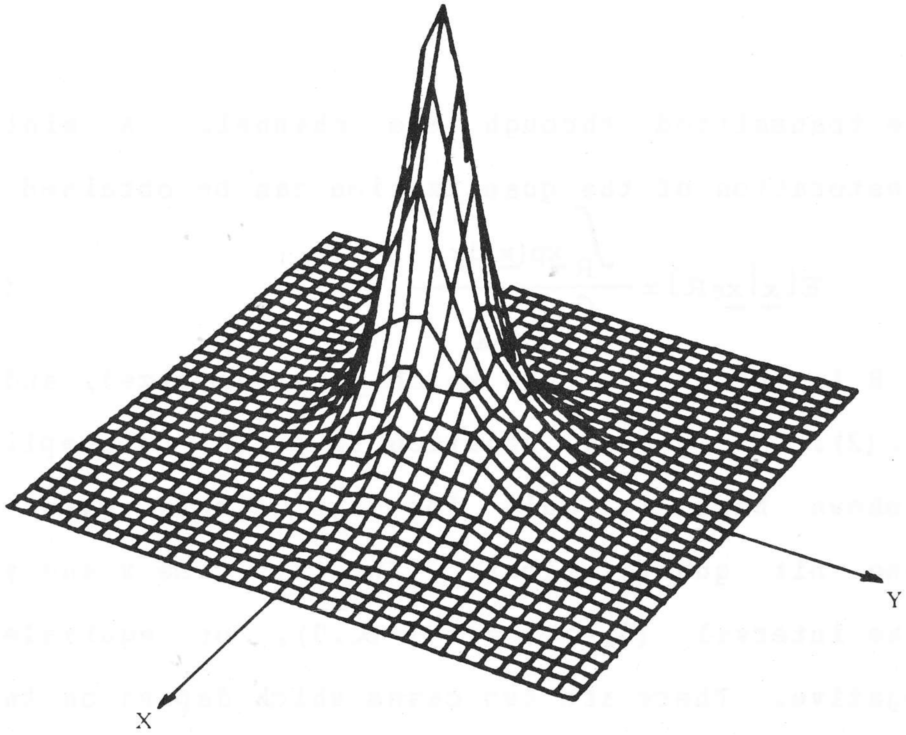
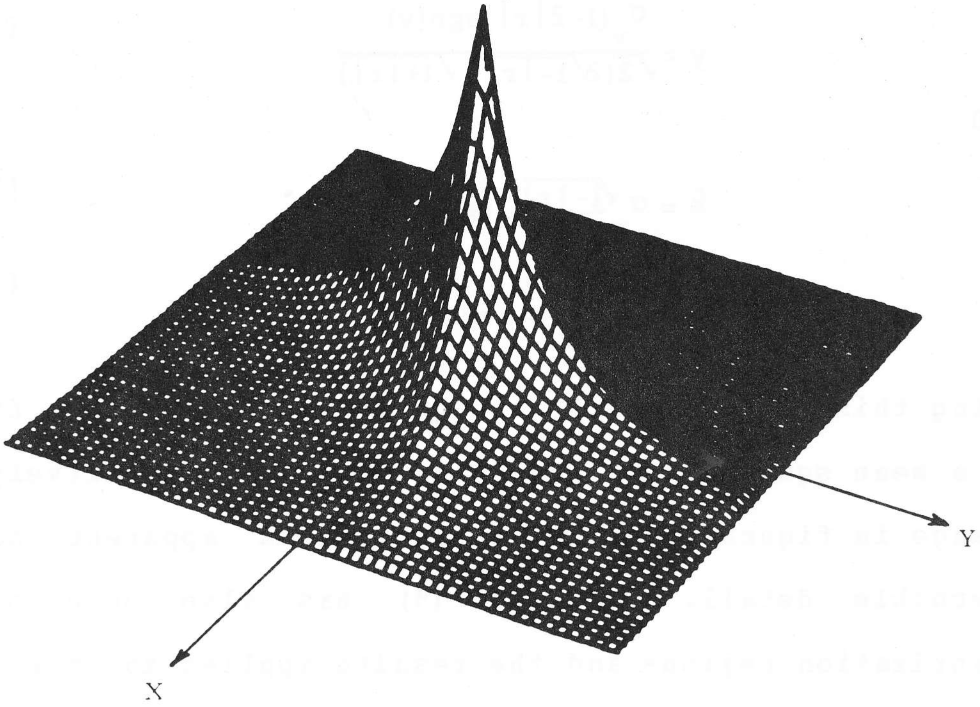


Figure 3.2-2. Histogram of the DPCM signal for the "girl" picture.



(a) Histogram of the DPCM coded "girl" image.



(b) Correlated laplacian density function; correlation = 0.4.

Figure 3.2-3. Two-dimensional distributions for DPCM simulations.

before they are transmitted through the channel. A minimum mean square error restoration of the quantization can be obtained <2> from

$$E\{\underline{x}\,|\,\underline{x}\in R\} = \frac{\int_R \underline{x}p(\underline{x})d\underline{x}}{\int_R p(\underline{x})d\underline{x}} \qquad (8)$$

where $\underline{x}=(x,y)$, R is the region into which $\underline{x}$ is quantized, and $p(\underline{x})$ is defined in eq. (2). The general solution to eq. (8) is complicated, so the solution shown here is only for the simple case of delta modulation (one bit quantization). In this case x and y are each quantized to the interval $(0,\infty)$ or $(-\alpha,0)$, or equivalently, as positive or negative. There are two cases which depend on the sign of the product of x, y, and the correlation, r. The results are

(a) $rxy>0$

$$\hat{x} = \frac{\sigma_x(1-2|r|)\,\mathrm{sgn}(x)}{\sqrt{2(2\sqrt{1-|r|}-\sqrt{1+|r|})}} \qquad (9)$$

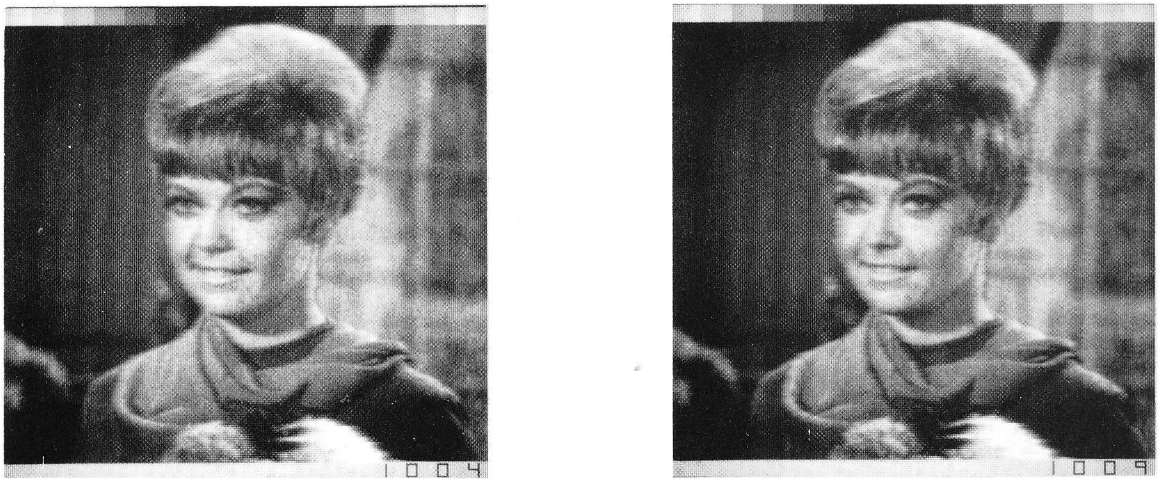
$$\hat{y} = \frac{\sigma_y(1-2|r|)\,\mathrm{sgn}(y)}{\sqrt{2(2\sqrt{1-|r|}-\sqrt{1+|r|})}} \qquad (10)$$

(b) $rxy<0$

$$\hat{x} = \sigma_x\frac{\sqrt{1-|r|}}{2}\,\mathrm{sgn}(x) \qquad (11)$$

$$\hat{y} = \sigma_y\frac{\sqrt{1-|r|}}{2}\,\mathrm{sgn}(y) \qquad (12)$$

Applying this restoration to the quantized image in figure 4a results in a mean square error reduction of 12%. Subjectively, as the restored image in figure 4b shows, there is less apparent noise and more discernible detail. Equation (8) has also been solved for general quantization regions and the results applied to the two and three bit coded images shown in figures 4c and 4e, respectively. The resultant images in figures 4d and 4f exhibit both a reduction in mean



(a) DPCM 1 bit/pixel

(b) 1 bit/pixel restored

(c) DPCM 2 bits/pixel

(d) 2 bits/pixel restored

(e) DPCM 3 bits/pixel

(f) 3 bits/pixel restored

Figure 3.2-4. Minimum mean square error restoration of DPCM coded images.

square error and a subjective improvement in quality. The subjective improvement is less apparent in these pictures, however, because the quantization itself is less noticeable.

Thus the technique described above provides an effective method for restoring DPCM coded images, particularly when the quantization is coarse. Further analysis is expected to extend the results to PCM coded image samples which have correlated Rayleigh distributions.

References

1. J. B. O'Neal, Jr., "Predictive Quantizing Systems (Differential Pulse Code Modulation) for the Transmission of Television Signals," Bell System Technical Journal, Vol. 45, May/June 1966, pp.689-721.

2. M. N. Huhns, "Transform Domain Spectrum Interpolation," University of Southern California Image Processing Institute Technical Report, USCIPI Report 530, March, 1974, pp.28-38.