SUGGESTED SCHEMES FOR ENCODING GREY LEVEL "BIT" PICTURES FOR TELIDON

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ABSTRACT

Currently Telidon PCM encodes grey level pictures using the "BIT" picture description instruction. Though this scheme is quite immune to channel noise, it does not take into account the high redundancies in the picture and as a result the time to transmit such a coded picture is significant. There are many alternative coding schemes (e.g. DPCM, transform, run-length, or block truncation) which may also be suitable. The current PDI standard has some openings for adopting one of these techniques.

The ideal coding scheme (1) should permit high compression, (2) should be extendable to colour images, (3) should have a high immunity to channel noise, (4) should require little hardware or firmware to decode the picture, and (5) should permit progressive re-construction of an image from low to high resolution.

Several well known coding schemes have been simulated in both software and firmware and are discussed in this paper.

RÉSUMÉ

Jusqu'à présent, les images monochromatiques du système Télidon ont été codées par modulation d'impulsions (PCM) et transmises au moyen d'une Instruction de Description d'Image (I.D.I.) prévue a cette fin. Quoique résistante aux effets du bruit, cette méthode ne permet pas une utilisation efficace de la capacité du canal de transmission. Il existe plusieurs techniques de codage, dont le PCM différentiel (DPCM) et les transformées unitaires, qui s'avèrent plus convenables.

Le code idéal devrait posséder les caractéristiques suivantes: (1) au taux élevé de compression des données et (2) une bonne immunité au bruit. Il devrait également (3) être extensible aux images couleur, (4) permettre la realisation d'un décodeur avec un minimum de matériel et de logiciel, et (5) préférablement reconstruire une image en affichant d'abord une première approximation de celle-ci et en y apportant ensuite des améliorations par un processus itératif.

Ce mémoire présente les résultats de la simulation de plusieurs de ces codes.

Introduction

The alphageometric coding of Telidon provides an elegant and powerful means of creating, storing and transmitting highly detailed colour graphic images. It is recognized, however, that there is a need to supplement the existing set of picture description instructions by the addition of a "photographic mode". The present standard allows the transmission of still photographic images by Pulse Code Modulation; existing Telidon terminals currently are capable of displaying only 8-grey level pictures. Clearly, it is desirable to both improve the quality of these images and reduce the amount of data required to represent them.

Unlike the coding of graphic information, there are numerous methods of compressing video images, each of which has particular advantages with regard to cost of implementation and efficiency. Furthermore, once it is decided to adopt a particular coding scheme, there is little freedom in selecting the techniques of implementation. A specific coding scheme may be an ideal tradeoff in terms of today's technology, however once it is selected, it is possible to become locked into this approach even when it becomes less cost effective than competing schemes.

This paper describes the various image coding techniques which are currently used and discusses their advantages and disadvantages. The coding schemes are compared with regard to their

(1) data compression ratio,
(2) immunity to channel noise,
(3) cost of realizing a decoder,
(4) flexibility
(5) quality of the decoded image.

The encoder complexity is considered to be of secondary importance, since its cost can be distributed over a large number of decoders. Item (4) refers to various features such as ease of extensibility to colour imagery or the ability to progressively reconstruct the image from low to higher resolution so that reception could be stopped when the desired image quality has been achieved.

Basic Concepts

Most of the image compression systems are structured similarly, so that it is useful to review the main results of rate distortion theory [1 and 2]. A digital monochrome image can be considered as an array of numbers x_{ij} which specifies the intensity levels of each element in the image. Normally the values of the neighbouring pixels are highly correlated which implies the presence of redundant information. Though the x_{ij} components are commonly digitized with between 64 to 256 grey levels, entropy measurements [3] indicate that the average information per pixel is between 1 and 2 bits. The object of source encoding is to transmit the picture at a low data rate while minimizing the average distortion.

Practical results of rate distortion theory are mainly limited to Gaussian source with squared-error distortion. Though it is questionable whether either assumption is appropriate to image communications [4], the basic ideas are used in nearly all encoding schemes. The first step is to reduce the redundancies in the data by applying a linear transformation on a block of data. The transformation is often reversible so that no loss of information occurs in this process. In the second step, the transformed components are quantized individually to the desired precision. The minimum quadratic distortion is achieved by encoding the components so that the error is Gaussian with constant variance over each component [1]. Methods of choosing the quantization levels for Gaussian and Rayleigh distributed sampled data have been found by Max [5], Roe [6], Algazi [7] and Pearlman [8].

The most serious deficiency of the rate distortion approach is that it does not take into account the psychophysical response of the human visual system. Recent attempts have been made to incorporate models of the human visual system in image coding [9] and [10] with excellent results for colour pictures.

In the remaining sections of this paper, we examine several commonly used image coding schemes. The literature in this area has become so vast (eg. [11] and [12]) that it is a difficult task to present an impartial view. Useful review articles and books on this subject are Habibi and Robinson [13], Andrews [14], Haskell and Steele [15], Gonzalez and Wintz [16], Pratt [17], Hall [18] and Stafford [19].

Differential Pulse Code Modulation (DPCM)

DPCM is used in applications where the cost and speed of the decoder are of primary importance. Its compression efficiency between 2 and 3 bits per pixel and its susceptibility to noise are inferior to more complex coding schemes, however it has been used successfully in transmitting digital colour TV pictures in real time [20, 21 and 22].

The basic DPCM coder consists of a predictor, a quantizer and a channel coder. The predictor uses the previous pixel intensities to predict the next pixel value. The difference between the actual value and the predicted value is quantized and channel coded. The decoder uses the coded differences to correct the predicted intensities based on the previous computed intensity levels. A feedback loop is inserted into the coder in order to ensure that the predictor in both the coder and decoder use the same pixel values.

The predictor attempts to decorrelate the pixel intensity values by subtracting the components which are correlated with the previous pixels. Letting x_{j-k} denote the intensity level of the k th previous neighbouring pixels, the n th order predictor is of the form

$$y = \sum_{k=1}^{n} l_k X_{j-k} \qquad (1)$$

The predictor coefficients l_k can be chosen to minimize the mean square error [23] but frequently they are approximated by simple numbers in order to avoid costly floating point operations [24] and [25]. If the neighbouring pixels originate from both the same and previous scan lines, the coding scheme is called 2-dimensional DPCM. Since the decoder must store the previous line in a buffer, 2-dimensional DPCM is more costly to implement; however, the compression efficiencies are superior to the 1-dimensional implementation. Habibi [26] has demonstrated experimentally that there is little improvement in the performance of the DPCM beyond the third order predictor.

As the number of quantization levels is reduced, it becomes increasingly difficult to keep the quantization distortion below the visual thresholds. This distortion appears as noise in dark uniform areas, (granular distortion), and blurring of sharp edges (slope overload). The mean square error is known to be a poor performance criterion for measuring the subjective quality of the image [27]; therefore the selection of quantization levels is based more on psychophysical groundsas opposed to statistical measures [4].

The distribution of differences between the predicted and observed intensity values is highly peaked around zero except in busy areas of the picture. In order to increase the compression efficiency of the DPCM, both adaptive techniques [28] and [29] and variable length coding schemes [16] have been used. Both methods result in a small increase in coding efficiency at the expense of considerable coder complexity. Ideally both the prediction coefficients and the quantization levels should be updated to match the local statistics of the image.

The susceptibility of DPCM to channel noise is one of its most serious drawbacks [30]. The errors appear as highly visible streaks which can be objectionable at even low error rates (10^{-6}). Various techniques for detecting the errors [31] and reducing their impact [24] have been tested experimentally. Some of these techniques reduce the coding efficiency by introducing a leak factor into the predictor [24] or adding error control protection [32].

Several other methods have been tried to improve the performance. These include a hybrid scheme [33] in which the image is transform coded in the horizontal direction and DPCM coded in the vertical direction. Hung [34] combined block coding techniques with DPCM achieving bit rates as low as 0.8 bits/pixel on a colour picture.

In summary, though DPCM is basically a simple coding scheme, the various extensions to this technique make it as complex as competing coding schemes. In addition, it would be difficult to establish a standard DPCM coding scheme for Telidon. Since both the coder and decoder must be implemented in exactly the same fashion, the scheme offers little future flexibility. For this reason, DPCM was rejected as a Telidon standard.

Block Transform Coding

Block transform coding [35] is still considered to be the most efficient coding scheme for digital images [36 and 37] and the least sensitive to channel noise [17]. It is more difficult and expensive to implement, but fortunately there is a wide choice of transforms with varying effectiveness and complexity.

The image is coded block by block, where a block is typically 16 by 16 pixels. The transform decorrelates the information in the matrix and concentrates the information into one corner of the matrix. The coefficients of the matrix are quantized and transmitted to the decoder.

Letting [X] represent the block of data, the transformation consists of two matrix multiplications

$$[F] = [U][X][V]^T \qquad (2)$$

where [U] and [V] are unitary matrices which act on the rows and columns of [X]. The optimum matrices can be estimated from the Karhunen-Loeve expansion [38], but this procedure is computationally too expensive for both the coder and decoder. Instead, suboptimal transforms such as the Hadamard transform [39], the Slant transform [40], the Cosine transform [41] or the Sine transform [42] are implemented, the Cosine transform being considered as the closest approximation to the Karhunen-Loève expansion [17]. The advantages of using such a deterministic transformation are: (1) there exist efficient methods for evaluating the transforms with computational complexity proportional to 2log N for an N by N block of pixels [43, 44 and 45]. (2) it is not necessary to transmit the unitary transform with the matrix [F].

The computational aspects become important for real time applications or when the algorithm is to be implemented on a microprocessor. Though the percent mean square error decreases with increasing block size (for fixed bit rate), the number of multiplications per pixel, the required arithmetic precision, and the buffer sizes all increase with the block size. Fortunately, the information in the picture is correlated in a small local area, making it unnecessary to use block sizes larger than 16 by 16 pixels [17]. Knab [46] has shown that the Hadamard transform is quite robust to roundoff errors.

The elements of the transformed block are generally uncorrelated, but have a large dynamic range, in particular the zero frequency component is always very large. Various methods have been used to quantize these components [17]; the most common scheme uses a bit map which allocates the number of bits to each frequency component. The allocation is based on the statistics of the picture, assigning more bits to those components with the larger variance. The method has been made adaptive [47 and 48] by defining 4 bit maps and assigning a particular block to one of these maps based on the statistics of that block. This is the most efficient compression scheme which is not based on psychophysical properties of the human visual system.

Provided that the bit maps have not become corrupted by noise, the coding scheme is reasonably insensitive to channel noise. A bit error is confined to one specific block and its effect is spread over the entire block. As a result, error rates of 10^{-4} are barely noticeable and levels as high as 10^{-2} are acceptable.

Another significant advantage of transform coding is that spatial filtering operations can be performed very efficiently in the transform domain. Hall [9 and 10] has utilized this property by incorporating a nonlinear mathematical model of the human visual system. Error levels were halved and the quality of the images degraded gracefully with decreasing data rates down to 0.1 bits per pixel.

The excellent performance of transform coding techniques suggest that it should be included into the Telidon standard. The most serious objection to this approach is the heavy computer requirements (eg. 8 floating point multiplications per pixel for a 16 by 16 block Cosine transform). The ensuing hardware and firmware costs are not a trivial consideration based on today's technology.

Block Truncation Coding (BTC)

BTC is a new coding technique which is most suitable for coding multilevel graphics [49, 50 and 51]. The technique consists of dividing the image into 4 by 4 blocks. For each block, a bit plane is transmitted which indicates whether each pixel in the block is bright or dark. Also transmitted are the quantized values of the mean and variance of the intensity levels. The receiver reconstructs the two-tone blocks with high and low values chosen so that the sample mean and variance are preserved in each block. Mitchell and Delp [49] achieve a bit rate of 1.4 bits/pixel for a 32 level graphics system. The coding system also has good immunity to channel errors and is easily implemented on a microprocessor.

Singular Value Decomposition (SVD)

The SVD is a special form of the general 2-dimensional transform [38]

$$[X] = [U][S][V]^T \qquad (3)$$

where [S] is now a matrix consisting of only diagonal elements. Because the off-diagonal elements of [S] are all zero, the inverse transform can be written in the simple form

$$[X] = \sum_{i=1}^{n} s_i u_i v_i^T \qquad (4)$$

where s_i is called the singular value associated with the singular vectors u_i and v_i. If the summation is truncated, the result is a least squares approximation to the matrix [X] [52]. Quantizing the singular values and vectors on the basis of rate distortion theory, Garguir [53] achieved compressions corresponding to 0.8 bits per pixel with little information loss. The advantages of this technique are (1) the simple decoding schemes, (2) its high immunity to noise and (3) its flexibility. For a 16 by 16 block, the number of multiplications per pixel is less than the corresponding number to perform the Fast Cosine Transform. Furthermore, computations can start as soon as the first pair of singular vectors are received. (The singular values can be incorporated into the singular vectors in order to save a multiplication.) If the Telidon decoder has 8 or more bit planes of raster memory, then the singular vectors can be ordered so that the decoder progressively reconstructs the image from low to high resolution [54].

The main disadvantage of the SVD is the considerable computational cost of the coding [52]. Since the coding need only be performed once and is then amortized over a large number of decoders, we do not consider this to be a serious drawback.

Illustrative Results

It is beyond the scope of this paper to present detailed experimental results of the authors' ongoing research in this area. Certain photographs are included here in order to illustrate the concepts and techniques discussed in the text. The standard IEEE photograph of the girl is felt to be representative of one class of imagery which might be effectively transmitted via a videotex system. With the exception of Figure 2a, all images have been magnified 2 times by pixel repetition in order to ensure that detail is not limited by the resolution of the display screen.

Figure 1 is the original 8 bit PCM image, and is included here for purposes of comparison.

Figure 2a, which is an enlargement of the girl's right eye, illustrates the operation of the Block Truncation Code with a block size of 4 by 4 pixels. It can be seen that there are as expected only two grey levels per block of 16 pixels. Figure 2b is the BTC image from which 1b was extracted and 2c shows the relatively high noise immunity of BTC at a bit error rate of 10^{-3}.

The photographs in Figure 3 depict certain characteristics of DPCM. It should be noted that the distortion of 3b and 3c have been deliberately accentuated to ensure their visibility on the printed page. Figure 3d dramatically demonstrates the high susceptibility of DPCM to channel noise. The image is seriously degraded at a bit error rate of 5×10^{-3}, which is not an unusually high figure for broadcast videotex (teletext) channels.

Figures 4a through 4d illustrate the progressive reconstruction of the Singular Value Decomposition with a block size of 16 by 16 pixels. The image reconstructed from 4 of the 16 singular planes is an excellent approximation to the original. Figure 5 shows the performance of the SVD in the presence of noise. It was necessary to use the extremely high error rate of 10^{-2} to fully demonstrate the effect of bit errors in the decoded image. It can be noted that because the decoder calculates the outer product of two vectors, a single bit error is reflected in all 16 pixels of one row or column of a 16 by 16 block. Figure 6 is a graph of the mean-square error in the SVD coded image as a function of the bits/pixel coding rate.

Conclusions

Unfortunately there is no image coding scheme which is clearly preferable to all others for Telidon applications. The transform schemes are considered to be superior in terms of (1) data compression ratio, (2) immunity to channel noise, and (3) quality of the decoded image but are computationally more complex than other approaches. The SVD is one exception which offers all the advantages of the transform coding schemes and in addition is relatively simple to implement on the decoder. Furthermore, the SVD is very flexible allowing progressive reconstruction of a still picture from low to high resolution without the penalty of performing more operations per pixel. The scheme behaves acceptably on our existing Telidon terminals which are capable of displaying 8-level grey pictures and will offer superior performance on the future higher resolution terminals.

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FIGURE 1, KODAK GIRL.
8 BIT PCM

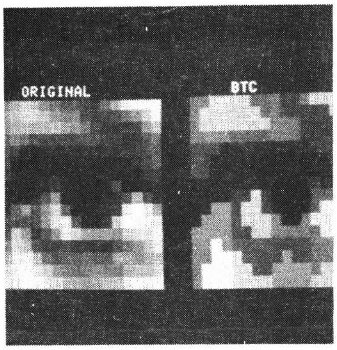

FIGURE 2A, ENLARGEMENT OF KODAK GIRL'S EYE, LEFT ORIGINAL, RIGHT BLOCK TRUNCATION CODING

FIGURE 2B, BLOCK TRUNCATION CODING OF KODAK GIRL

FIGURE 2C, BLOCK TRUNCATION CODING WITH 10^{-3} ERROR RATE

FIGURE 3A, 7 LEVEL DPCM CODING OF KODAK GIRL

FIGURE 3B, 3 LEVEL DPCM CODING OF KODAK GIRL. THE CHOSEN LEVELS ILLUSTRATE SLOPE OVERLOAD

FIGURE 3C, 3 LEVEL DPCM CODING OF KODAK GIRL. THE CHOSEN LEVELS ILLUSTRATE GRANULAR DISTORTION.

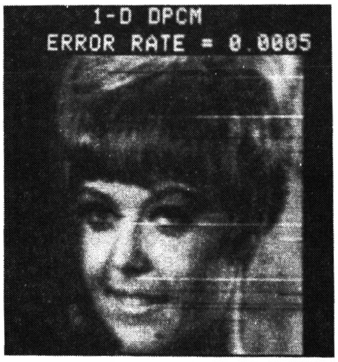

FIGURE 3D, 1-D DPCM CODING IN THE PRESENCE OF 0.0005 BIT ERROR RATE.

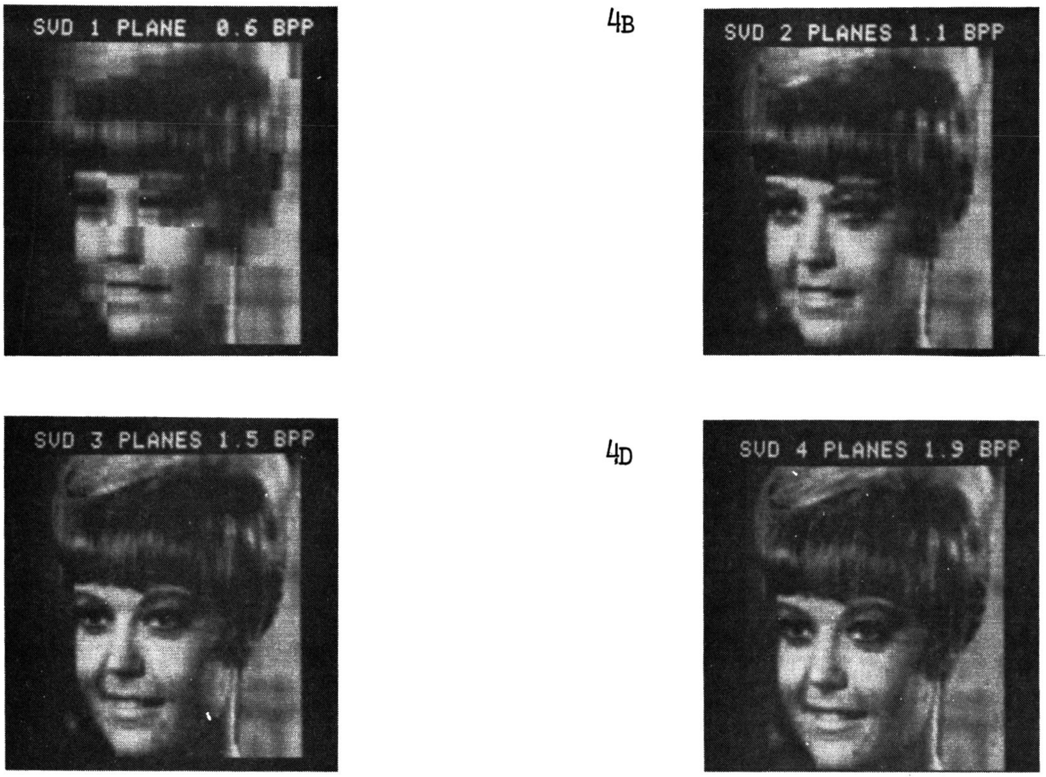

FIGURE 4 (A,B,C AND D) PROGRESSIVE RECONSTRUCTION OF KODAK GIRL WITH 1, 2, . AND 4 SVD PLANES.

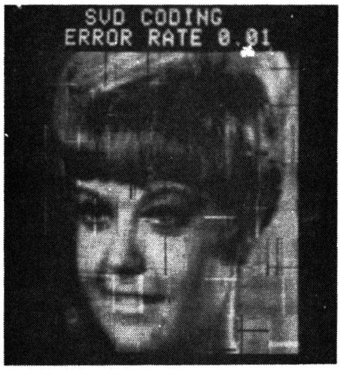

FIGURE 5, SVD RECONSTRUCTION OF KODAK GIRL IN THE PRESENCE OF 10^{-2} BIT ERROR RATE.

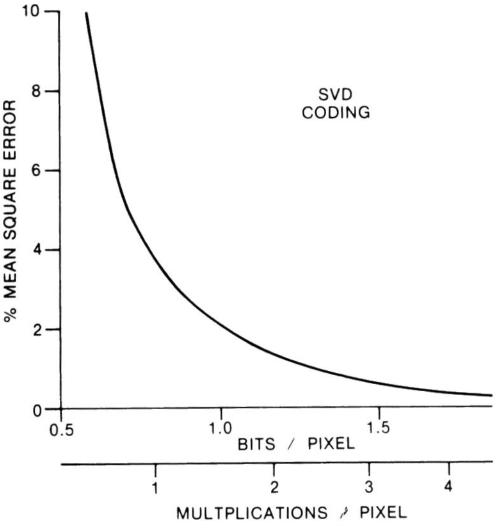

FIGURE 6, MEAN SQUARE ERROR AS A FUNCTION OF BITS/PIXEL CODING RATE AND MULTIPLIES PER PIXEL.