ABSTRACT: Advances in computer technology and mass storage have paved the way for implementing advanced data compression techniques to improve the efficiency of transmission and storage of images. The present paper deals on the development of a data compression algorithm suitable for images received from satellites. The compression ratio of 1.91:1 is achieved with the proposed technique. The technique used is 1-D DPCM Coding. Hardware-relevant to coder has also been proposed.

INTRODUCTION: This paper is devoted to the new algorithm developed using 1-D DPCM for satellite images. It could be extended to 2-D images. Comparison with other coding techniques which are used for the same images are also given.

Satellites which are in orbit for remote sensing are LANDSAT, SPOT, IRS-1A and MOS-1. The successful launching and operationalisation of IRS-1A spacecraft has established the value of satellite based earth’s resources observation. Image data compression is necessary for satellites for speedy data transmission, effective image processing to extract the desired information and easy interaction between the user and a distant archive. SPOT an European satellite has used 1-D DPCM for image data compression but could achieve a compression ratio of 1.33:1 (3) ISRO - Bangalore is working image data compressor for IRS-1A. In this connection they tried with Hadmard Coding and got 2:1 compression ratio. Now they are trying with different transform coding techniques to achieve a compression ratio of 10:1. The ability of compressor is based on data compressing ability, minimum reconstruction error and easy implementation. Based on these considerations 1-D DPCM Coding for IRS-1A images is designed. Further the advantages of both DPCM and transform coding can be used to design hybrid coders.

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NOTE: The work has been done during August 1990 - January 1991.
PREDICTIVE CODING: The technique exploits the redundancy in the data. Predictive Coding is best suited for the real time on line transmission because of the ease and the economy with which they can be implemented. A common data compression method utilizing predictive coding is DPCM (Differential Pulse Coded Modulation). Predictors based on recent waveform history and time variant predictor coefficients lead to a class of coders which constitutes an example of low-to-medium complexity designs. These predictor gives high quality digitization at bit rates in the order of 3 or 4 bits/sample. By representing a correlated video signal in terms of difference samples or prediction error samples one can achieve an increased SNR at a given bit rate or reduction of bit rate for a given requirement of SNR. The DPCM coder consists of predictors and quantizers. The linear 1-D predictor uses previous elements in the same line. The overall system of 1-D DPCM Coder-decoder is shown in Fig. 1.

The quantizer input in a DPCM coder is prediction error or a difference signal, given by:

\[ d(n) = x(n) - \hat{x}(n) \]

\[ x(n) \quad \text{original sample} \]

\[ \hat{x}(n) \quad \text{prediction based on many previous input samples} \ x(n-1), x(n-2) \ldots x(n) \]

By using feedback prediction the transmitter and receiver estimate could be made identical and hence reconstruction error accumulation could be minimised.

DESIGN OF PREDICTORS: If we assume a linear predictor using previous samples \( x_1, x_2, \ldots x_n \) to predict sample \( x_o \) then prediction is given by:

\[ \hat{x}_o = \sum_{k=1}^{N} a_k x(n-k) \quad k = 1 \ldots N : \text{Order of predictor} \]

\[ a_k = a_1, a_2, \ldots a_n : \text{Predictor coefficients} \]

Predictor coefficients are nothing but auto correlation functions which quantifies the closeness of the 2 samples as a function of their time or space separation. It is a function that tells how close and similar samples \( x(n) \) and \( x(n+k) \) are on average.

\[ a_k = \frac{R_{xx}(k)}{R_{xx}(o)} \]

\[ R_{xx}(o) \quad \text{Variance of the signal} \]

\[ R_{xx}(k) \quad \text{Auto correlation coefficient} \]
For non zero mean signal $R_{xx}(k)$ can be calculated as follows:

$$R_{xx}(k) = \frac{1}{N} \sum_{n=0}^{N-|k|-1} (x(n) - \bar{x}) (x(n+k) - \bar{x})$$

$\bar{x} = \text{mean of the signal}$

The quantity $A_k$ has the value in the range of $(-1, +1)$.

ORDER OF PREDICTORS: Variation of prediction error as a function of $N = 1, 2, 3$ is described. For analytical simplicity prediction based on past unquantized samples are taken.

First Order Predictor: Uses one previous sample of the same line for prediction

$$\hat{x}_{(n)} = H_1 x_{(n-1)}$$

Optimum value of $H_1$ is calculated by minimizing variance of the prediction difference

$$H_1 - \text{opt} = A_1$$

Second Order Predictor: Uses 2 previous samples on the same line for prediction.

$$\hat{x}_{(n)} = H_1 x_{(n-1)} + H_2 x_{(n-2)}$$

Considering the mutual correlations between the samples optimum values for $H_1$ and $H_2$ are calculated as follows:

$$H_1 - \text{opt} = H_2 - \text{opt} = \frac{A}{1 + A^2}$$

Third Order Predictor: Uses 3 previous samples on the same line for prediction,

$$\hat{x}_{(n)} = H_1 x_{(n-1)} + H_2 x_{(n-2)} + H_3 x_{(n-3)}$$

$$H_1 - \text{opt} = H_2 - \text{opt} = 1; \quad H_3 - \text{opt} = -1$$

SOFTWARE REALIZATION: The simulation flow chart for 1-D DPCM coder and decoder is given in Fig. 2. The image of 512 x 512 is divided into block of 16 x 16 pixels. For 1-D purpose lx16 pixels are taken. Autocorrelation coefficient for each line is calculated and averaged for 512 lines. For many images auto correlation coefficient is
calculated and by using the design optimum values of auto correlation functions are calculated.

Thus ACF for First and Second Order Predictor are 0.875 and 0.5. The algorithm for first and second order is given below:

\[
\begin{align*}
\hat{x}(n) &= 0.875 \ x(n-1) + d(n-1) \quad \text{First Order} \\
\hat{x}(n) &= 0.5 \ x(n-1) + d(n-1) + 0.5 \ x(n-2) + d(n-2) \quad \text{Second Order}
\end{align*}
\]

\[
\begin{align*}
d(n) &= x(n) - x(n) \\
d(n) &= \text{DPCM error} \\
\tilde{d}(n) &= d(n)/q \\
q &= \text{quantisation level}
\end{align*}
\]

The quantisation process is simply a floating point to integer round off conversion. To fix up the quantisation levels, the histogram for DPCM errors have been developed, from which limits for quantisation level for each DPCM error can be determined. This histogram procedure is done for a large set of images to make the quantisation level to be fixed as a unique one which can be applicable to any image. The histogram of 2nd order predictor for some images are shown in Fig. 3. The bits are allocated according to the preselected patterns which ensures as far as possible that \( B_i - \log_2 \left( \frac{E}{q} \right) \) where \( B_i \) is the \( i \)-th component, \( E \) is proportional to DPCM error and \( q \) is quantisation level for transmission.

In order to reduce the transmission error the first pixel in each block is transmitted as an 8 bit number. Thus 1 x 16 pixels are transmitted as follows:

Thus for a minimum mean square error of 0.001% the bits are reduced from 128 to 68. At

\[
\begin{align*}
x_1 & \quad \ldots \quad x_{16} \quad \text{Pixel with 8 bit/sample} \quad \text{total = 128 bits} \\
\tilde{d}_1 & \quad \ldots \quad \tilde{d}_{16} \quad \text{DPCM error at the end of transmitter} \\
\tilde{d}_1 & \quad x_1 \quad 7 \text{ bits} \\
\tilde{d}_2 & \quad 5 \text{ bits} \\
\tilde{d}_3 - \tilde{d}_{16} & \quad 4 \text{ bits/pixel} \quad \text{total = 68 bits}
\end{align*}
\]

the decoder the same predictor is used to reconstruct the image. Reconstruction error, mean square error, error histogram, compression ratio are all done by another program. The compression ratio for different quantization steps are calculated and tabulated in Table I. Fig.4 shows the graph of mean square error vs. Bit/pixel. The simulation is done for
LISS 1, LISS 2, LTM, SPOT and Cotton Images. The photograph of a original and reconstructed image is attached.

PROPOSED HARDWARE: The Fig. 5 shows block schematic of second order DPCM coder by software realization. It is designed using only adders and registers. The coder consists of Predictor

- Quantizer/Limiter
- Adders
- Loop delays and bit serializers

By shifting register once to right is equivalent to multiplying by 0.5. Two D-F/F are used to store 2 previous predicted samples. A 4 bit ALU is used as adder/subtractor. For regular layout the quantiser and limiter is designed using ROM. All the possible combinations of inputs are decoded in the row decoder and programmed by bit line outputs. The appropriate limiting table being selected by control input to furthur ROM address line. The required bits are then selected from the ROM output and passed to the serializer and to the prediction loop adder. The control signals to the limiter, bit selector and the bit serializers come from another ROM whose inputs are the sequence being processed and the selector for required bit rate.

DPCM DECODER: The decoder consists of input buffer, bit paraller, inverse quantiser and the adder and the same predictor as that of coder. By using VLSI technology the design could be made very simple and used for real time applications.

COMPARISION WITH OTHER CODING SCHEMES:

PCM: Basic PCM affords simplicity compare to DPCM but suffers from in-efficiency since it does not use redundancy present in video signal. By using 1-D DPCM bit rate is reduced to 4 bit/pixel in comparision with 8 bit/pixel (PCM) with the same quality of reconstructed image. Compared to PCM, in DPCM error variance is decreased, hence the improvement in SNR.

Transform Coding: The performance of higher order predictor is superior to all 2-D transform technique, when the system is optimised for a particular picture. In concerned with implementation, TC coders are more complex. They require array multipliers, a complex inverse transformation, buffer requirements. Thus hardware complexity, cost and delays involved are all in favour of DPCM coding. However, for more realistic case of unmatched statistics, the performance of DPCM system changes significantly while change in the performance of transform technique is relatively small. But addition of variable length coding scheme to DPCM system further improves the performance. For a
compression ratio of 2:1 the M.S.E. performance of present 1-D DPCM is same as that obtained in Hadamard transform technique. But in DCT transform coding MSE performance is better for a higher compression ratio compared to 1-D DPCM. Further hybrid coding could be designed using DCT transform and 1-D DPCM for 2-D images. Bit rate is reduced to 1-0.5 bit/pixel by hybrid coding.

CONCLUSION: First, second and third order predictors are tried and it is noted that second order DPCM with optimised ACF gives better compression ratio. The coder design is based on minimum mean square criteria. Through simulation result it is observed that there is not much improvement in MSE or SNR in third order predictor but it increases the hardware. Thus second order predictor with minimum hardware gives the same quality of picture that obtained by PCM. A compression ratio of 2:1 is achieved using uniform quantization. The hardware suitable for implementing the scheme is proposed.

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Fig (1) a. DPCM CODER  b. DPCM DECODER

Fig (2) SIMULATION OF DPCM CODER-DECODER
Fig (3) Second Order Error Histogram

Fig (4) Graph of Mean Square Error Vs. Bit Rate
Fig(5) PROPOSED DPCM CODER

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<th>COMPRESSION RATIO</th>
<th>BITS/PIXEL</th>
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TABLE-I