Compression & Decompression Techniques For Satellite E-O Images

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Abstract: Image coding or compression is an important issue in case of E-O image transmission and storage. Elimination of spatial and/or temporal redundancy from sequential scene samples can be used to reduce the amount of required data to be transmitted or recorded to that needed to represent the "new" information in each sample set. The aim of image compression is to reduce the bandwidth or signal spectrum required by a radio relay data link and/or data recorder. It is also used so that more data can be carried over a channel with fixed bandwidth. Lowering the signal bandwidth permits reducing the power output required of the data link tra *Keywords*: SAR, DPCM technique, Land Cover, Texture Analysis nsmitter and still maintaining a good overall Signal-to-Noise ratio. Another reason for using data compression is so that detecting and correcting bits can be added to data stream to overcome the effects of transmission errors and different types of jamming.
From among the three preferred types of data compression usually employed in space imagery, the choice is generally made based upon the amount of image degradation allowable, and cost. For an eight bit quantized image, the one dimensional DPCM can usefully applied down to 2-1/2 to 3 bits per sample or even beyond; while transform coding schemes have been shown to 1-1/2 to 2 bits per sample or somewhat beyond. For practical purposes then, a compression scheme, which reduces the need to record or transmit the scene data to a rate approaching 2 to 3 bits per sample, is recommended. For a single bit per sample can be assured in instances where this provides the only satisfactory answer and the budget is in a place to afford it.
This paper represents a review of techniques used for coding of digital images; it shows the most proper technique to be used with E-O payloads. Predictive coding is presented, analyzed, simulated, and tested for the image of Minea area (Egypt) and the results are displayed [4].

Keywords: PCDM, DPCM technique, Predictive Coding, Coding Rate

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1. Introduction

Data compression is possible because of several factors. The first one is that most objects are not randomly in appearance and have some regularity. Data compression is also possible because the eye is insensitive to certain types of errors. For example, at steep edges the eye cannot accurately judge the change in signal amplitude. The edge itself is the mean feature of interest. Therefore edges do not have to be accurately described in amplitude although they must be depicted accurately in their spatial extent. Basic compression techniques are listed here:

1. *Null compression* replaces a series of blank spaces with a compression code, followed by a value that represents the number of spaces.
2. *Run-length compression* expands on the null compression technique by compressing any series of four or more repeating characters. The characters are replaced with a compression code, one of the characters, and a value that represents the number of the number of the characters to repeat [9] .
3. *Key word encoding* creates a table with values which represent common sets of characters. Frequently occurring words like *for* and *the* or character pairs like *sh* or *th* are represented with tokens used to store or to transmit the characters.
4. Huffman statistical method assumes there is a varied distribution of characters in the data. In other words, some characters appear more than others. The more frequently the character is occurring, the fewer bits used to encode it. A table is created to store the encoding scheme and, in the case of a data transmission, this table can be passed to a receiving modem so it knows how to decode the characters [8-10].

Paper [4] introduced a short review of transform coding technique and detailed analysis of DPCM technique to achieve the best reconstruction of a decoded image. The paper displayed the simulation and results of coding the digitized image of Minea area using DPCM technique with different number of bits per picture element. The paper was terminated by a short reference to contour coding of images as an introduction to the second generation of image coding techniques, which achieve high compression ratio.

Because compression algorithms are software-based, overhead exists that can cause problems in real time environments, but compression during backup and archiving of files poses few problems. The use of high-performance techniques can help eliminate most of the overhead and performance problems.

New developments in the field of large-scale integration make new possible and powerful components. These include high-speed A/D converters, large buffer memories, high-speed multipliers and microprocessors. Data compression is also possible through the use of what is known as entropy coding.

2. Transform Coding

ElMinya Governorate is located in Upper Egypt. It is located between 28° 47′ 52″ N and 32° 37′ 33″ E. Figure 1 show location map of ElMinya Governorate.

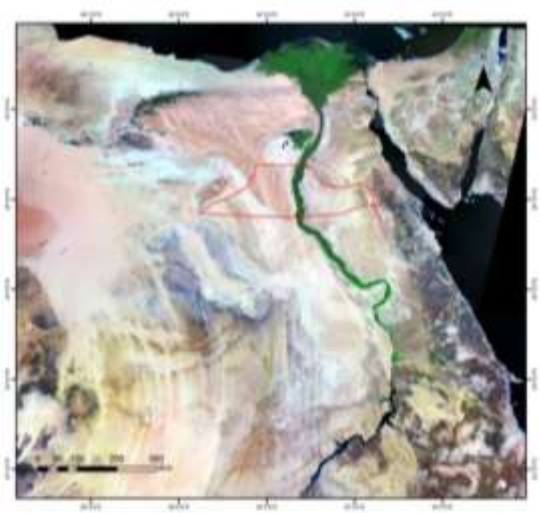


Figure1 LOCATION MAP OF ELMINEA GOVERNERATE

In transform coding, the image is divided into sub-images and then each of these sub-images is transformed into a set of more independent coefficients. The coefficients are then quantized and decoded for transmission. At the receiver, the received bits are decoded, and inverse transformed to recover intensities of picture elements 9 - , and 10 - . Achieved compression results from dropping smaller coefficients and coarsely quantizing the others as required by the image quality Performance of a transform coder is determined by the shape and size of sub-images, type of transformation used, selection of the coefficients to be transmitted and quantization of them, and the bit assignor which assigns a binary word for each of the quantized outputs. The optimum transform must achieve smallest mean-square reconstruction error, maximum energy compaction in the smallest number of coefficients and result in uncorrelated transform coefficients. The transforme that achieves these requirements is the Karhunen-Loeve transform (KLT). The optimum transform is computed from the covariance function of the vector U (in one-dimensional case).

3. Entropy CODING

One common method of data compression is the utilization of differential pulse code modulation 11 - , 12 - , 13 - , and 14 - . In this technique the beginning of a line is transmitted with a full 8 bit. However subsequent pixels are merely transmitted as changes from the previous pixel's value. This permits about a 2:1 reduction in the data rate. However, since zero changes or changes of only +1 or –1 gray level are the most common, it is possible to further compress the data by using an entropy code. The code is shown in the middle column for progressively later adjacent level changes. Therefore, as shown in the last column form table 1 the more frequently encountered small changes are given very few bits and more bits depict the more infrequently encountered changes 15 - -19 - . This can further reduce the data rate sometimes by more than 2:1.

DPCM ERROR TO BE TRANSMITTED	CODE TRANSMITTED	TOTAL NUMBER OF BITS TRANSMITTED
0	0	1
+1	10	2
-1	110	3
+2	1110	4
-2	11110	5
+3	111110	6
-3	1111110	7
1	1	
1	1	
1	1	

Few bits for most common occurrences

More bits for less common occurrences

Table 1 ENTROPY CODING

4. Storage System Compression

Before discussing compression algorithms for file storage, we should understand that file compression is different from disk encoding, which is commonly employed by disk drives to pack more digital 1s and 0s onto physical surface of a disk. File compression squeezes the characters and bit strings in a file down to a smaller size and takes place in software before the file information ever gets to the write head of the hard drive. Modern hard drives that use encoding simply accept the streams of 1's and 0's from the CPU and pack them into much smaller space than is possible if encoding is not used

I. A magnetic recording system such as a hard drive records information by changing a magnetic field over the disk surface. A change in the field between two possible states is called flux transition. In simple terms, a flux transition can represent a digital one and the absence of transition can represent a digital 0. Encoding provides a way to represent more digital information per flux transition. Modified frequency modulation (MFM) stores digital 1's as a flux transition and 0's as the absence of flux transition. Encoding techniques include the following:

- *Run length limited (RLL)* Represents bit patterns as codes, which can be stored with fewer changes in magnetic flux, improving on MFM storage capabilities by 50 percent.
- *Advanced run length limited (ARLL)* doubles the density of MFM recording by converting patterns into codes that can be stored in the flux transitions that are four times as dense.

Because disk encoding is automatically handled by the disk drives at the hardware level. The disk drive has a certain capacity that is obtained using an encoding scheme but this encoding scheme is rarely of interest after the purchase as long as the drive has the capacity you need.

Temporarily storing the data to be compressed permits real time its analysis directly after receiving the data on the ground. Depending upon the nature of the statistics of the information to be compressed, the characteristics and operating parameters of the data compressor can be then varied in advance of actually transmitting the analyzed information. This permits to use few transmitted bits for large "flat" areas of little detail and many more bits to properly describe "busy" areas of the scene.
Furthermore, if the satellite flies over large areas which are completely busy, the degree of data compression can be adapted in advance to prevent overload and the complete loss of information from some parts of the scene. Hence data compression can be "smart", adaptive and intelligent. The encoder's decision is transmitted in advance to the decoder via a very few powerful added "mode" or "decision" bits that constitute a preamble.

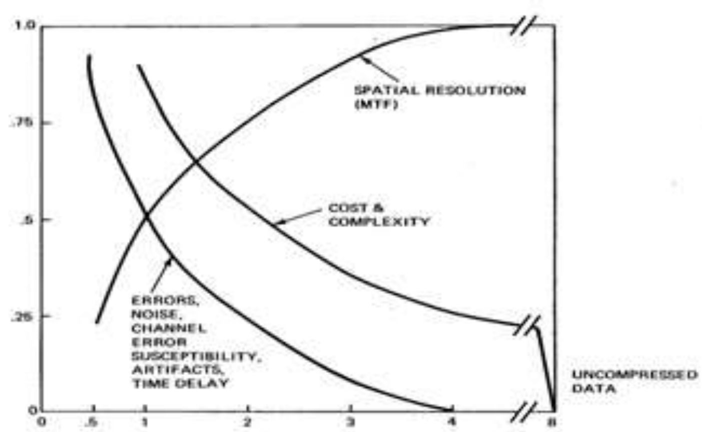
When using one or two dimensional transform technique errors due to random noise and deliberate jamming only affect the transformed data. Therefore when it is "untransformed" the errors are spread out over large areas of scene and constitute only a small portion of the total amplitude of any one particular pixel. Therefore such jamming is easily disregarded by the photo interpretators.

It is also possible to minimize or even remove some types of data link transmission errors at the receiver through sophisticated data analysis techniques. This might eliminate the need for adding extra error detecting and correcting bits, which would otherwise penalize the overall data rate.

3. PARAMETRIC PERFORMANCE CHARACTERISTICS OF DATA COMPRESSION SYSTEMS

Figure 1 shows a normalized plot of what happens as the data rate (expressed in bits /pixel) is reduced from initial uncompressed value of 8 bits per pixel. By the time the data is compressed to about 3 bits per pixel the spatial resolution in most common data compression systems starts to fall off significantly. By the time it reaches two bits it is very noticeably degraded and at 1 bit per pixel the resolution is not even one half of the original system value. This occurs in virtually all-conventional data compression techniques at these large data compression rates.
As the data rate is reduced below one bit per pixel the cost and complexity increases very markedly.

The final curve shows: errors, noise channel error susceptibility, artifacts and time delay. These are generally noticeable above 4 bits per pixel but below that increase considerably and at a half bit per pixel they are very definitely possible.



DATA RATE, BITS/PIXEL

Figure 1 GENERAL DATA COMPRESSION PARAMETRIC PERFORMANCE CHARACTERISTICS

5. Effects of the Quantization Without Data Compression

On the left column of the table 2, the numbers of digital encoding bits are shown from 8 down to 1. The second column shows the number of uniform steps that are represented by this number of encoding bits. At 8 bits per pixel the original image is generally completely indistinguishable from the original. By deleting two bits and only using six bits per pixel one obtains an image which is about minimum for good quality. At five bits per pixel a phenomenon called false contours occurs. These contours are noticeable to the human observer but have no actuality on the scene. Therefore they are considered to be objectionable.

At four bits per pixel signals smaller than one sixteenth or six percent of the peak- to- peak amplitude are lost. This is particularly objectionable since many systems have a modulation transfer function, which decrease significantly at the higher spatial frequencies where single pixel phenomenon may occur. Having such a coarse quantization means that Nyquist frequency objects may well be completely lost. Of course at one bit per pixel one has a black/white picture clipped at 50% amplitude point.

NUMBER OF DIGITAL ENCODING BITS	NUMBER OF UNIFORM STEPS	COMMENTS
8	256	INDISTINGUISHABLE FROM ORIGINAL
7	128	
6	64	MINIMUM FOR GOOD QUALITY
5	32	FALSE CONTOURS PRODUCED LOOSE
4	16	SMALL AMPLITUDE DETAILS. – PARTICULARLY OF SMALL TARGETS
3	8	
2	4	
1	2	BLACK-WHITE OUTLINES AT 50% AMPLITUDE POINT

Table 2 EFFECTS OF QUANTIZATION

5.1 COMPRESSION ERROR VISIBILITY

Compression errors become visible at 0.25% mean-square error or 5% RMS error. This is because the eye can discern about a five percent difference in tone between adjacent areas. This is equivalent to about 4 ½ bits per pixel using straight pulse code modulation.

5.2 DATA COMPRESSION PROBLEM

In the Figure 2 the central picture indicates that as the analog video output of the sensor goes from 0 to 256 levels. The goal is to transmit video digital levels proportional to analog video outputs. This is shown by 45° line in the central picture.

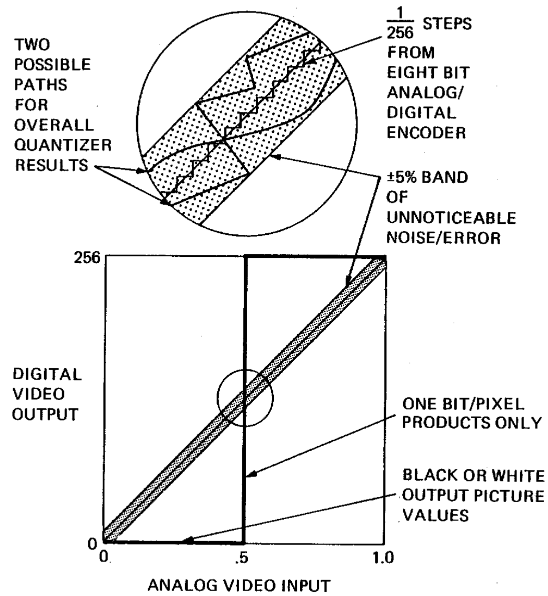


Figure 2 **THE DATA COMPRESSION PROBLEM: HOW TO CONVEY 256 LEVELS (8 BITS) OF INFORMATION BY USING ONLY 2 LEVELS (1BIT)**

However because the eye cannot distinguish less than +/- 5% immediately adjacent area changes, there is actually a band shown dotted around the nominal transfer characteristic wherein the human eye cannot distinguish errors. This is shown enlarged at the top of the page. For the full 256 levels caused by eight bits per pixel the uniform size staircase lays right in the middle of this acceptable band. However it is possible to utilize other amplitude transfer characteristics. These are shown by other possible paths for the overall quantizer. It is seen that it can be quit curved and even have backward going steps. This is one of the eye's "defects" which are capitalized upon in data compression techniques.

6. Coding Rate of Image Coding Techniques

Figure 3 shows the performance of various encoding techniques versus the data compression rate in bits per pixel. Basic pulse code modulation can be used from 8 bits per pixel down to about 5 bits per pixel. Higher up on the graph is shown more and more sophisticated techniques. Some of these are not applicable in E-O payloads. For example inter-plane techniques which rely on multiple viewing of the same area. Also many bars are shown divided into two parts, one is the non-adaptive or conventional type approach and the second bar is an adaptive one. In the later the information is temporarily stored and analyzed first and the parameters of the compression technique are adapted intelligently to the type of data to be transmitted. As is quite evident, the adaptive techniques provide a considerable additional reduction in the average data rate. Also it is seen that below one bit per pixel it is mandatory to use a transform in either one or two directions or even between successive frames in the more conventional television type system. This always reflects itself in increased costs, size, power and complexity.

Image coding is concerned with the minimization of the number of information carrying units used to represent an image. Image compression is useful in image transmission and storage where the aim is to minimize the bandwidth for transmission and memory for storage where the aim is to minimize the bandwidth for transmission and memory for storage. The efficiency of any coding algorithm is measured by its data compressing ability, the resulting distortion of decoded image, and its implementation complexity. Image coding techniques comprise: transform coding, pulse coding modulation (PCM), predictive coding (DPCM), hybrid coding, and miscellaneous techniques that do not fall into any of the above categories.

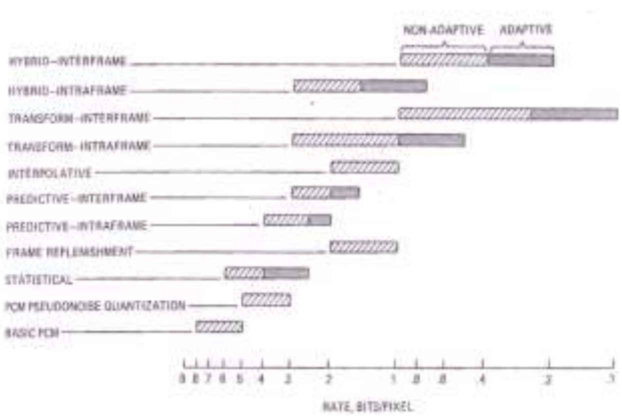


Figure 3 CONDING RATE OF IMAGE CODING SYSTEMS

7. Effect of Differential Pulse Code Modulation=

Figure 4 shows the large step that occurs on the left side of the figure. However because up to 4 pulses are transmitted as one word to describe the difference between the stored output and the input, it is possible for 16 (2^4) different quantization step sizes to be utilized for transmitting the error signal.

Therefore in the region of certain steps, it is seen that the step sizes increase considerably and therefore a much better job of following the input signal is possible.

On the right side, the granular noise still produces grain in the picture.

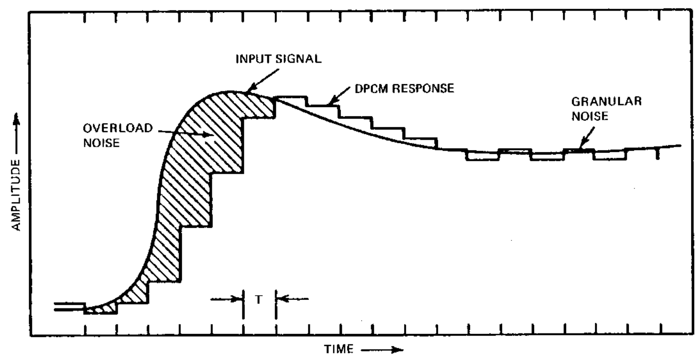


Figure 4 **ILLUSTRATED VIDEO WAVEFORM AND DPCM RESPONSE SHOWING A SLOPE OVERLOAD REGION AND A GRANULAR NOISE REGION**

The effect of image, noise, and visual response non-stationary in noise restoration is a function of the type of filter that is chosen for the restoration. Stationary filters such as wiener, parametric, inverse, and low – pass require estimates of signal and noise power spectra with estimation errors resulting in suboptimal spatial frequency weighting. Statistical filter such as maximum – likelihood (ML), Maximum a posteriori (MAP), Linear–Least–squares (LLS), and Bayesian estimation require some knowledge about the signal and noise with errors resulting in suboptimal spatial domain.

To determine analytically which type of filter performs better for an ensemble of images would be quite difficult, so resort is often made to empirical comparisons where it has been shown that at least for noise restoration statistical filters are superior.

Image noise restoration and predictive image coding are combined by implementing a maximum – a – posteriori (MAP) estimator on the differential signal in a differential pulse code Modulation (DPCM) image compression scheme as in figure 5. For a Laplacian differential – signal probability density function (pdf) and a Gaussian noise (pdf), the MAP estimator is an adaptive coring operator which is linear in the encored region with a bias toward zero and a null operator in the cored region.

The bias and the width of the coring region are functions of the noise and differential – signal variance, which are estimated from local image statistics over variable length line segments. Independent segments are isolated by using a generalized – likelihood – ratio – test (GLRT) for laplacian signals to determine whether or not adjacent segments have statistically equivalent differential variances. Because the MAP operator is an additive bias, it can be inserted in the transmitter of a DPCM encoder with error build – up or overhead information. Since it lowers the variance of the signal to be quantized by reducing the noise it can simplify the encoder by decreasing the number of levels that are required [6].

8. Conclusion

A review of image coding techniques has been presented. Computer simulation of 4 different DPCM systems is performed. The results indicate better performance in using adaptive optimum quantizer in the feedback loop of the encoder.
The results of computer simulation indicated the followings:

1- The optimum quantizer performed approximately 1 bit behind the rate of distortion function,
2- There are significant differences in the subjective quality of the decoded image between the 3 predictors which contain an optimum quantizer. This is due to the nature of the used image which contains large areas of slowly varying grey levels, requiring only 1 bit for coding when an optimum quantizer is used in the feedback loop of the coder. The 2^{nd} optimum encoder has the smallest one while the previous element encoder has the largest one.
3- The subjective quality of the decoded image using optimum quantizer in the feedback loop is much better than those resulting when non optimum quantizer is used. The quantizer degradations are very clear in the last case. Image segmentation and contour coding is under investigation as high compression coding techniques. In this technique, image is segmented into adjacent regions and the signal in each region is approximated by 2 dimensional polynomial function. Polynomial coefficients are chosen to minimize the mean square reconstruction error between the actual pixels in a region and their approximation. Then contours are coded using chain coding and polynomial coefficients are coded as binary values to the largest possible degree of the quantization precision [5].

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