COMPARATIVE INVESTIGATION OF A NON-LINEAR PREDICTIVE CODEC VERSUS JPEG LOSSLESS COMPRESSION

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ABSTRACT

A non-linear predictive coding based algorithm is proposed in the paper for lossless image compression. The algorithm uses two neighbouring pixels, one left and the other top, as a pioneering block to search for the best matched blocks inside a pre-defined window. The corresponding pixels associated with the best matched blocks are then taken to produce the predictive value, together with the two pioneering pixels. Comparative investigation is carried out by experiments which show clearly that the proposed algorithm outperform JPEG lossless compression mode.

1. INTRODUCTION

Modern computers systems are now required to handle not only numbers and text, but also multi-media data types, including images. Such systems have only been made possible by the rapid evolution of CPUs, storage media and transmission channels. However, the requirements in terms of storage space and transmission bandwidth for image and other multi-media data still outstrip the capabilities of current hardware. Therefore, image compression is an important topic in the current era of multi-media computing. Images can be compressed using lossy methods, so long as the image quality after compression is acceptable (i.e. visually indistinguishable from the original). There are a number of key application areas, however, notably the compression of X-ray images, in which distortion or error cannot be tolerated. Hence, lossless image compression provides a fruitful area of research for this type of applications.

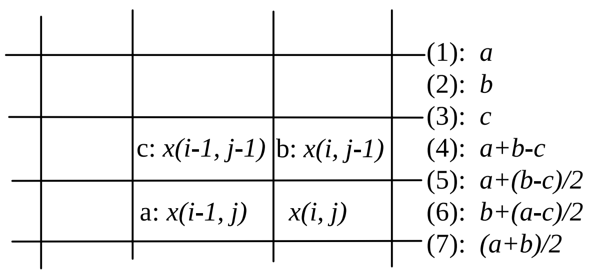

Figure 1 *JPEG predictive patterns*

The existing technology in lossless image compression can be summarised in two directions. One is predictive coding based algorithms such as JPEG lossless image compression mode. It uses seven linear combinations of three neighbouring pixel values to produce the predictive value for the image pixel to be encoded. The seven different types of predictive pattern can be illustrated in Figure 1, in which all the predictive patterns are constructed by fixed coefficients, a, b, and c. The prediction is proved to be simple and efficient[1-2]. The ideal case is that the predictive value perfectly matches all the pixels to be encoded, which means that the image is completely compressed to one pixel. On the contrary, the worst case is that no part of any pixel is predicted, or completely out of match between the predictive value and the pixel to be encoded. In this case, no compression is achieved by predictive coding. Variations such as the so called lossy plus lossless method[4] are also included in this direction which involves using a lossy compressed image to optimise the prediction.

The other direction in lossless image compression is by directly using the entropy coding, or general lossless data compression algorithms to compress images. Since images are normally digitised from quantizing analogue data, this type of direct entropy coding method often shows inefficiency compared with their performances in text compression. Typical examples include arithmetic coding[6], Huffman coding[6], and Ziv-Lempel dictionary based entropy coding[5] etc. These types of algorithms simply take each pixel as one symbol, output codes are then produced either by its probability estimation or by a process of sorting and matching between those entries in the established dictionary and the input strings. This type of compression techniques can also be viewed as applying entropy coding directly to image pixels without its normal pre-processing. In JPEG standard, the selection value is 0 corresponding to no prediction[1-2].

In our work, a non-linear predictive coding algorithm is proposed to achieve lossless compression of images. The algorithm is tested and assessed by using JPEG as the bench mark. The rest of the paper is organised into three sections in which section 2 describes the algorithm design, section 3 reports experimental results and section 4 draws conclusions based on the investigation carried out in section 3.

2. NON-LINEAR PREDICTIVE CODING

Predictive coding based image compression can be modelled as an induction inference problem in which a conditional probability distribution of future pixels is learned from the past. Given the past pixels, it is desirable to predict the next pixel by assigning a conditional probability distribution to it under the condition that the probability assigned to the entire sequence of input image data is maximised. Starting from the theoretical results on universal modelling[7], further

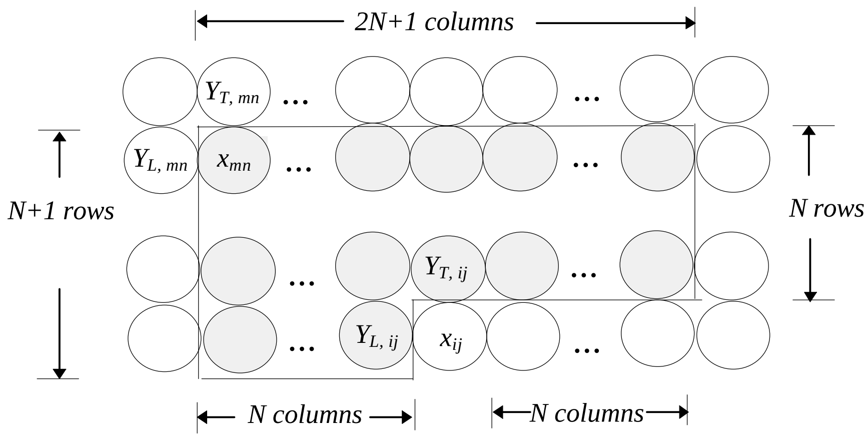

Figure 2 *Predictive context out of the pioneering pixels and the search window definition*

optimisation can be conducted to tune in the model into a more specific one by reducing the model classes or number of parameters[9] such as lumping together those equivalent states in finite-memory sources. The lumping operations on contexts can be formed out of quantization. Hence, vector quantization based predictive coding can actually be designed to reduce the modelling cost[8]. The side effect, however, is the slow speed incurred by vector quantization of all those previously encoded pixels before the context is constructed. Reference [8] simplified the quantization process by using Euclidean distance to search for those patterns with which the distances from the current neighbouring pixels are kept minimum. Predictive value is then produced by those pixels associated with the searched patterns. Prompted by the refined universal context modelling, we propose a new yet simple non-linear predictive coding based algorithm to achieve lossless compression of grey-scale images.

Specifically, for each pixel, x_{ij}, to be encoded, its neighbouring pixels are normally used as the context to produce a predictive value. In our algorithm, we define two pioneering pixels, $Y_{L,\,ij}$ and $Y_{T,\,ij}$, out of its left neighbour and top neighbour. This is illustrated in Figure 2. Following the definition of pioneering pixels, a search window is further constructed to include those previously encoded pixels which are most likely to be correlated to x_{ij}. For the convenience of experiments and assessment, we design the window size controlled by one number represented by N as shown in Figure 2. The non-linear predictive coding is carried out in two stages. In the first stage, we search the window for those best matching pixels to select predictive candidates. Since each pixel inside the window has its own two neighbours, one left and one top, one pioneering block can be constructed for every pixel inside the window. Therefore, the selection can be carried out by calculating the distance between the two pioneering pixel blocks, one for the pixel to be encoded, and the other for pixel inside the window. Let x_{nm} be those pixels inside the window, and $Y_{L,\,mn}$, $Y_{T,\,mn}$ be the two pioneering pixels, the search can be conducted by calculating the following squared Euclidean distance:

$$d(x_{mn}, x_{ij}) = (Y_{L,\,ij} - Y_{L,\,mn})^2 + (Y_{T,\,ij} - Y_{T,\,mn})^2 \qquad (1)$$

Associated with the minimum distance, $d_{min}(x_{ij}, x_{mn})$, corresponding pixels inside the window can be selected as the predictive candidates. Due to the fact that there may be a number of pixels which associated distances are equally minimum, the number of candidates can be represented by M. The second stage involves the calculation of the predictive value for x_{ij} from the selected candidates and the two pioneering pixels. The predictive value is simply produced by the following equation:

$$P_{ij} = \frac{\sum_{k=1}^{M} X_k}{M} + \frac{Y_{L,ij} + Y_{T,ij}}{2} \qquad (2)$$

The idea is that since the pioneering pixels are the immediate neighbours of x_{ij}, they should play the major roles in the prediction. Firstly, the two pixels are used to classify those pixels inside the window to ensure that only correlated pixels are selected for the prediction, and secondly the two pixels themselves should also make significant contributions to the prediction.

Therefore, the proposed non-linear algorithm can be designed into the following steps:

1) For each pixel to be encoded, construct a pioneering block which contains two neighbours, one on the left and the other right at the top.
2) Search in the pre-defined window for the best match of these two pioneering pixels via the squared Euclidean distance as shown in equation (1).
3) Pick up the block with minimum distance as the best match and identify the associated pixel. In circumstances that more than one block has the same minimum distance, all the associated pixels should be selected. The so called associated pixel has the same position as that of the pixel

to be encoded where in the best matching block, one pixel is its left neighbour and the other its top neighbour.

4) Produce predictive value as given in equation (2).
5) Entropy coding by Huffman algorithm the same as JPEG.

The decoder can be easily designed in the same way as that of encoder which simply reverse the operations specified in the above 5 steps. Finally, further work can also be initiated by taking tree structures[9] into consideration to organise the predictive model.

Table I *Experimental Results In Compression Ratios*

Image Samples	JPEG	Proposed 1	Proposed 2	Proposed 3
baboon	20.21	20.96	20.45	20.36
barb	31.36	32.20	33.36	33.65
boat	38.79	40.48	40.10	39.98
jet	44.79	45.16	44.63	44.37
lena	43.97	45.31	45.23	45.10
peppers	37.72	39.62	39.26	38.96
zelda	45.18	46.66	46.48	46.34
truck	39.31	39.70	39.10	38.90
bridge	23.33	24.24	23.63	23.47
camera	38.07	39.25	39.30	39.15
clown	36.03	37.03	36.59	36.25
salad	31.52	32.65	31.84	31.45

Table II *Further Experiments on Non-Linear Predictive Coding*

Image Samples	JPEG	*N = 1*	*N = 2*	*N = 3*
baboon	20.21	18.66	17.39	17.15
barb	31.36	32.28	34.40	35.09
boat	38.79	39.94	39.03	38.84
jet	44.79	44.06	43.10	42.74
lena	43.97	43.90	43.44	43.30
peppers	37.72	38.07	37.39	37.07
zelda	45.18	44.64	43.98	43.73
truck	39.31	37.65	36.39	35.98
bridge	23.33	22.41	21.11	20.85
camera	38.07	38.78	38.66	38.41
clown	36.03	36.68	35.72	35.08
salad	31.52	30.74	29.46	28.84

3. EXPERIMENTAL RESULTS VERSUS JPEG

To test the proposed non-linear predictive coding algorithm, a group of 13 image samples are selected for our experiments. The samples are listed in the first column of Table I. To ensure a fair comparison with JPEG[10] lossless compression, the proposed algorithms tested use the same Huffman coding as the entropy coding. The algorithm is implemented in connection with the size of the search window and a comprehensive test is carried out on Sun sparc stations. The experimental results are illustrated in Table I where all figures represent compression ratios which are defined below:

$$\textit{Compression Ratio} = 100 \times \frac{S_O - S_C}{S_O} \tag{3}$$

where S_O stands for the size of original image files and S_C for the size of compressed image files. In Table I, the name of the proposed algorithms also reflect the size selection of the pre-defined searching window. Propose 1, for example, means $N = 1$ and Proposed 2 means $N = 2$ etc. From the experiments shown in Table I, it can be seen that the proposed 1 constantly outperforms JPEG for all the image samples. With proposed 2 and 3, the compression performance is better than JPEG for majority of the test images.

As the window size is relatively small in the Proposed 1, the time consumed for running both encoding and decoding is about the same as JPEG. With Proposed 2 and 3, the running speed is slight slower compared with JPEG. Searching speed can be further improved for the proposed algorithms if the implementation is optimised by fast algorithms which are successfully used in vector quantization.

Another set of experiments are also carried out prompted by reference [8] to provide further comparison with our proposed algorithm. The prediction is constructed based on the following equation:

$$P_{ij} = \frac{\sum_{k=1}^{M} X_k}{M} \qquad (4)$$

While the rest of coding is maintained the same as JPEG such as Huffman entropy coding etc., the experimental results for the same group of image samples can be illustrated in Table II where *N* stands for the size of the window. The Table shows that the algorithm occasionally provides better compression ratios than JPEG, but constantly being inferior to the proposed 1. In addition, we also tested both algorithms when the value of *N* is further increased. Unfortunately, it is found that no further improvements can be achieved.

4. CONCLUSIONS

In this paper, we have presented a non-linear predictive coding based algorithm for lossless compression of images. The algorithm improved JPEG's neighbourhood prediction by introducing a pioneering pixel search within a pre-defined searching window to locate those correlated pixels before its neighbourhood prediction value is produced. Extensive experiments are carried out in comparison with JPEG lossless compression mode. The assessment proves that the proposed algorithm provides better compression performance for all the image samples tested.

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