EVALUATION OF LOSSLESS COMPRESSION METHODS FOR GRAY SCALE DOCUMENT IMAGES

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ABSTRACT

In this paper, a comparative study of lossless compression algorithms is presented. The following algorithms are considered: UNIX compress, gzip, LZW, CCITT Group 3 and Group 4, JBIG, old lossless JPEG, JPEG-LS based on LOCO, CALIC, FELICS, S+P Transform, and PNG. In cases where the algorithm under consideration may only be applied to binary data, the bitplanes of the gray scale image are separated, with and without Gray encoding, and the compression is applied to individual bit planes. Testing is done using a set of document images obtained by gray scale scanning of prints of the eight standard CCITT images and a set of nine gray scale pictorial images. The results show that the highest compression is obtained using the CALIC and JPEG-LS algorithms.

1. INTRODUCTION

Compound document images may be composed of text, graphics and photographs and may be stored in gray scale or color format. When such documents are compressed without any information loss, they present a challenge, because the chosen compression method should perform well in regions with text/graphics and in regions with photographic content. Lossless compression algorithms have received increasing attention in the past decade [1-3], however, there have been few studies that evaluate their performance when applied to gray scale images. The objective of this paper is to provide a comparative assessment of several state-of-the-art lossless compression algorithms in the framework of continuous-tone document images. A number of algorithms including standards for lossless compression of bitonal and gray scale images are included in this study [4-7]. Two data sets are used containing gray scale document and pictorial images, respectively. The results can be extrapolated to cases involving color documents [8] and compound documents consisting of both text and pictures.

2. LOSSLESS COMPRESSION METHODS

Lossless compression methods may be categorized into sequential, where image pixels are typically visited in a raster scan fashion, and transform, where multiresolution decomposition of the image is used to obtain a hierarchical description of the image and allow for progressive transmission [7]. The problem of lossless compression involves the general steps of data modeling and data encoding [9]. The modeling part of the system is designed to provide an estimate of the probability of each symbol at the time of coding. Symbol coding may involve a variety of coders, such as Huffman [10], arithmetic [11], Golomb-Rice, etc.

The number of lossless compression methods is too large to include all of them in this study. The particular algorithms that are employed in this paper were chosen based on practical considerations and may be classified in two major categories: methods that operate on individual bitplanes and methods that operate on the entire gray scale image. The algorithms in these categories are overviewed next.

2.1 Lossless Compression of Bitonal Images

Bitonal image compression methods may be applied to images with more than one bit per pixel by separating the bitplanes and processing them independently. Gray encoding is sometimes used to reduce the redundancy between bitplanes [13,14]. However, even with Gray encoding there is a possibility of data expansion in the least significant bitplanes, which largely consist of noise. Therefore, it is worthwhile check for negative compression in the least significant bitplanes and apply these compression methods selectively. The following methods were considered.

LZW: Ziv-Lempel (LZ77 and LZ78) and Ziv-Lempel-Welch (LZW) are substitutional compressors based on generic data coding schemes [12]. They are efficient to implement, and widely used in utilities such as UNIX compress, gzip, and zip.

Group 3 and Group 4: The most common methods for bitonal image compression are CCITT Group 3 (G3) and CCITT Group 4 (G4) facsimile algorithms [5-7].

JBIG. The joint bilevel imaging group (JBIG) algorithm is based on JBIG allows for multiresolution processing and progressive coding, and offers improved compression over G3 and G4 by a factor ranging from 2 to 10, depending on the images type [2-7].

2.2 Lossless Compression of Gray Scale Images

Old Lossless JPEG. The first lossless JPEG algorithm never gained much popularity. Encoding is based on differential pulse code modulation (DPCM) followed by Huffman coding.

JPEG-LS: The New Lossless JPEG. The new standard for lossless JPEG compression is based on a variation of the low complexity lossless compression method (LOCO-I) [15]. The LOCO algorithm combines good performance with efficient implementation, without arithmetic coding. It also allows for a near-lossless mode, where the compression level depends on the maximum reconstruction error specified. The LOCO algorithm employs nonlinear predictors on causal neighborhoods, as defined by gradient information. Context modeling is designed to reduce the number of free parameters defining the coding distributions at each context, while avoiding context dilution. For a given context, the encoder adapts to the best Huffman code chosen from a fixed set that is matched to single parameter, exponentially decaying distributions. Efficient implementation is achieved through adaptive Golomb-Rice coding. Finally, redundancy is reduced by embedding an alphabet extension in flat, low-entropy regions.

CALIC. The context-based adaptive lossless image coding (CALIC) algorithm was a strong candidate for consideration as a new lossless JPEG compression standard [16]. It has been demonstrated that its performance is comparable to that of the Universal Context Modeling method [13]. The CALIC method is based on a context adaptive nonlinear predictor that operates in either binary or continuous-tone modes, depending on the context of the current pixel. In the continuous-tone mode, gradient adjusted prediction takes place and is further improved by error feedback, where prediction errors are modeled under different contexts, resulting in reduced conditional entropies. The coding step may involve either Huffman or arithmetic coding.

S+P Transform. The Said-Pearlman (S+P) transform is a separable transform that allows for perfect image recovery by truncating the transform coefficients during the transformation and encoding all of the transform coefficients [17]. The S+P transform based on the S transform, which is similar to the Haar wavelet image representation and allows for either progressive fidelity or progressive resolution implementations. The S+P transform utilizes information from both the low- and high-resolution bands for prediction and truncates the prediction value to an integer for efficient implementation. This transformation reduces the entropy in the resulting image representation, which is then encoded using either Huffman or arithmetic encoding.

FELICS. The fast, efficient, lossless image compression system (FELICS [18] combines the prediction and error modeling steps by utilizing the two nearest neighbors of a pixel in a raster scan order to estimate the probability distribution of the pixel intensity. Based on a parameter estimation method, the most suitable error model is chosen from a set, and the intensity is encoded using the Rice code of the model.

PNG. The Portable Network Graphics (PNG) is an image file format that is recommended as a web standard by the Word Wide Web (W3) Consortium [19]. Its compression scheme uses preprocessing to remove data redundancy, that is followed by the deflate algorithm that is also used in gzip.

3. RESULTS

Results were obtained for two image sets using the algorithms discussed above. The first set (GCCITT) consists of eight document images (1728 x 2376 x 8 bits per pixel), obtained by scanning prints of the CCITT fax images at 200 dpi with an HP desktop scanner. The second set (PICS) consists of nine gray scale pictorial images that are commonly used in image processing (airplane, baboon, boats, goldhill, bridge, cameraman, couple, lena, and peppers). The results for the methods that operate on the entire gray scale image are shown in Table 1. The best performers are CALIC with arithmetic encoding and JPEG-LS, followed by CALIC with Huffman encoding, the S+P transform with arithmetic coding, and FELICS. The compression obtained for the document images consistently better than that obtained for the pictorial images. This result is attributed to two reasons: (a) the document images have uniform background that allows for better compression; (b) the document images have larger dimensions, which typically means they can be compressed more effectively.

The results for the methods that operate on individual bitplanes are shown in Table 2. In general, JBIG outperforms the other methods. The striking effects of negative compression are obvious in the case of pictorial images, where data expansion takes place. It is also demonstrated that decorrelation of the bitplanes obtained by Gray encoding improves the results in some cases. These results can be improved by preventing negative compression, as shown in Table 3. This is accomplished by compressing only the bitplanes for which compression is positive. It should be noted that JBIG is the least sensitive to negative compression compared to G3, G4 and LZW. Negative compression is likely to take place in bitplanes associated with least significant bits. At these bitplanes, the image structure breaks down, since the information content is mostly due to noise, and the symbol probabilities deviate significantly from the models assumed by the bitonal compression methods, resulting in deterioration in performance.

4. CONCLUSIONS

This paper focused on the evaluation of several commonly used algorithms for lossless compression of continuous-tone pictorial and document images. Practical limitations prevented testing of some algorithms, but most of the standard ones were considered.

The major result is that the CALIC and JPEG-LS algorithms outperformed the others. This result is consistent with the findings of the JPEG committee, which chose JPEG-LS as the new lossless JPEG standard by considering not only performance, but also ease of implementation issues. However, an important issue that is not investigated here is the compression/decompression speed and relative implementation complexity of each algorithm. The fact that different algorithms were implemented in different platforms and that most of the available code was not optimized prevented meaningful comparisons at this stage.

We hope that this work will stimulate further benchmarking studies for diverse sets of images including pictorial, document, medical, remote sensing, and others.

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	Raw data	**Unix Compress**	**Gzip**	**CALIC (arith)**	**CALIC (huff)**	**FELICS**	**old JPEG**	**JPEG-LS LOCO-I**	**S+P (arith)**	**SP (huff)**	**PNG**
GCCITT	8	4.06	4.09	3.28	3.43	3.71	4.01	3.38	3.60	3.95	3.89
PICS	8	6.99	6.53	4.47	4.57	4.90	5.09	4.58	4.63	4.91	4.90

Table 1. Compression Results in Bits-Per-Pixel: Methods Operating on the Entire Image.

	RAW data	**LZW**	**Group 3**	**Group 4**	**JBIG**
GCCITT	8	5.28	6.96	7.16	3.99
PICS	8	8.18	10.91	10.92	6.22
GrayEncoded* GCCITT	8	4.35	4.35	4.26	3.70
GrayEncoded PICS	8	7.25	9.31	9.17	5.36
***Gray Encoding combines bitplanes using XOR**					

Table 2. Lossless Compression Results in Bits-Per-Pixel: Methods Operating on Individual Bitplanes.

BPP	**RAW data**	**LZW best****	**Group 3 best****	**Group 4 best****	**JBIG best****
GCCITT	8	4.40	4.57	4.43	3.85
PICS	8	6.70	6.77	6.58	5.90
GrayEncoded* GCCITT	8	4.35	4.35	4.26	3.70
GrayEncoded* PICS	8	6.14	6.21	5.92	5.14
***Gray Encoding combines bitplanes using XOR**					
****"best" prevents negative compression**					

Table 3. Lossless Compression Results in Bits-Per-Pixel: Methods Operating on Individual Bitplanes without allowing for Negative Compression.