A BIT-PLANE APPROACH FOR LOSSLESS COMPRESSION OF COLOR-QUANTIZED IMAGES

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ABSTRACT

Palette reordering is a well-known and effective approach for improving the compression of color-indexed images. The performance of most of the existing palette reordering methods has been evaluated using the compression rates attained by image coders which are based on predictive or transform coding technology, such as JPEG-LS or JPEG2000. In this paper, we show that image coding technology based on bit-plane coding, such as the one used by JBIG, provides a competitive performance in this class of images. Also, we present a palette reordering algorithm, adapted for bit-plane based encoders, that gives good results and is faster than Memon's or the modified Zeng's methods, the two most effective palette reordering algorithms.

1. INTRODUCTION

Due to failing to comply to the smoothness assumption, the compression of color-indexed images is a challenging task to most general purpose continuous-tone image coding techniques. In fact, a color-indexed image is represented by a matrix of indexes (the index image) and by a color-map or palette. Each index points to a color-map entry, establishing the corresponding color of the pixel. For a given image, this mapping can be arbitrarily permuted. However, although the final color image remains the same, the different internal representations may lead to index images that impose different degrees of difficulty for most continuous-tone image coding techniques, such as JPEG-LS [1, 2] or lossless JPEG2000 [3–5]. In other words, different mappings may imply dramatic variations in the compression performance.

Palette reordering is a preprocessing method that seeks a suitable permutation of the palette, with the aim of increasing the smoothness of the image of indexes and, consequently, of improving compression (for a survey, see [6]). These preprocessing techniques do not require post-processing nor side information. The number of possible configurations for a table with M colors corresponds to the number of permutations of M objects, i.e., $M!$. It is obvious that, unless for a few cases where M is small, the optimal solution cannot be found in practical time, which motivated several sub-optimal, lower complexity, proposals.

In this paper, we address the palette reordering problem from a point of view that differs from that of previous works. In fact, the majority of the methods that have been developed have been assessed using coding technologies based on predictive and transform coding. Notable examples of the use of those technologies are the JPEG-LS and JPEG2000 standards. In this work, we show that JBIG [7–10] exhibits a quite interesting performance in this class of images. Moreover, we present a palette reordering algorithm that was developed with the purpose of being used as a preprocessor for bit-plane based encoders. This reordering method gives good results and is faster than Memon's method and the modified Zeng's method, which are the two most effective palette reordering algorithms that are currently known [6].

The remainder of this paper is organized as follows. In Section 2, we briefly introduce the three image coding standards addressed in this paper, namely, lossless JPEG2000, JBIG and JPEG-LS. In Section 3, we present a bit-plane based palette reordering algorithm. Experimental results are given in Section 4. Finally, in Section 5, some conclusions are drawn.

2. STANDARD METHODS

JBIG, JPEG-LS and JPEG2000 are state-of-the-art standards for coding digital images. JBIG is mainly dedicated to the compression of bi-level imagery, whereas JPEG-LS provides lossless compression of continuous-tone images. JPEG2000 was designed with the aim of providing a wide range of functionalities.

JBIG (Joint Bi-level Image Experts Group) was issued in 1993 by ISO/IEC (International Organization for Standardization / International Electrotechnical Commission) and ITU-T (Telecommunication Standardization Sector of the International Telecommunication Union) for the progressive lossless compression of binary and low-precision gray-level images

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(typically, having less than 6 bits per pixel) [7–10]. JBIG is based on an adaptive context-based arithmetic coder, working on a bit-plane basis. More recently, a new version, named JBIG2, has been published [11], introducing additional functionalities to the standard, such as multi-page document compression, two modes of progressive compression, lossy compression and differentiated compression methods for different regions of the image [10].

JPEG-LS was developed by the Joint Photographic Experts Group (JPEG) with the aim of providing a low complexity lossless image standard that could be able to offer better compression efficiency than lossless JPEG [1, 2, 5]. Part 1 of this standard was finalized in 1999. JPEG-LS relies on prediction, residual modeling and context-based coding of the residuals. Most of the low complexity of this technique comes from the assumption that prediction residuals follow a two-sided geometric probability distribution and that, therefore, can be optimally encoded using Golomb codes.

JPEG2000 is the most recent image coding standard [3, 5] (Part 1 was published as an International Standard in the year 2000). This standard is based on wavelet technology and EBCOT coding of the wavelet coefficients, providing very good compression performance. JPEG2000 allows the generation of embedded code streams, meaning that from a higher bit-rate stream it is possible to extract lower bit-rate instances without the need for re-encoding.

3. BIT-PLANE BASED REORDERING ALGORITHM

The bit-plane based reordering algorithm that we propose in this Section has been inspired by the work of Fojtík *et al.* [12]. The aim of this method is to permute indexes in such way that the resulting binary images of each bit-plane contains less and larger regions, improving the compression. To better understand the idea, we present an example in Fig. 1, where the most significant bit-plane (MSB) of the image "peppers" is shown before and after the reordering procedure. As can be observed, the preprocessed bit-plane contains less and larger regions, a characteristic highly desired by most image coders.

The method starts by performing the analysis of the adjacency of the intensity values in the neighborhood of each pixel. This is given by the function $w(i, j)$, which is responsible for conveying the information of how frequently the pairs of neighboring pixels occur in the image. The neighborhood configuration is depicted in Fig. 2.

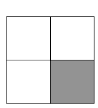

Fig. 2. Configuration of the neighboring pixels, in relation to the pixel in gray, for constructing the function $w(i, j)$.

The image is processed in a bit-plane basis, starting from the most significant bit-plane and proceeding to bit-planes below it. The operation of the algorithm is such that modifications performed in lower bit-planes do not affect already processed (upper) bit-planes.

Let us assume that there is some initial division of indexes into two groups, G_1 and G_2. For each group, we choose the index that has more relations with the other group than with its own group. These two indexes are swapped between groups. The process is repeated until the swapping procedure does not reduce the number of relations between the two groups. Since the algorithm proceeds from the most to the least significant bit-planes, the task now is to split G_1 and G_2 into four groups in the bit-plane below (G_{11}, G_{12}, G_{21} and G_{22}). The swapping approach is similar to that described above, but, to maintain the already processed bit-planes intact, the swapping procedure is only allowed between some groups: Elements of G_{11} can be swapped with elements of G_{12} and elements of G_{21} with elements of G_{22}. Figure 3 provides a schematic view of the procedure.

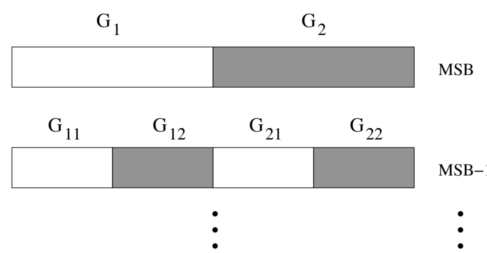

Fig. 3. The division of the indexes begins in the most significant bit-plane (MSB). Swapping is only allowed between groups G_1 and G_2 in the MSB and between groups $G_{11} - G_{12}$ and $G_{21} - G_{22}$ in the bit-plane bellow it. In the remaining bit-planes, the procedure is identical.

4. EXPERIMENTAL RESULTS

In this Section, we present experimental compression results, based on a set of images that have been already used in [13]. These are images from both synthetic and natural origins and of various sizes and number of colors[1]. The color palette of each of these images has been reordered using Memon's method, the modified Zeng's method (mZeng), and the bit-plane based method described in this paper.

Compression results are given for JPEG-LS[2], for lossless JPEG2000[3] and for JBIG[4]. The compression results ob-

[1]These images can be obtained from `ftp://www.ieeta.pt/~ap/images/synthetic` and `ftp://www.ieeta.pt/~ap/images/natural2/256`.

[2]Using V2.2 of the SPMG JPEG-LS codec with default parameters (`http://spmg.ece.ubc.ca`).

[3]Using the JasPer 1.700.2 JPEG2000 codec with default parameters (`http://www.ece.uvic.ca/~mdadams/jasper`).

[4]JBIG compression was obtained using version 1.6 of the JBIG Kit package (`http://www.cl.cam.ac.uk/~mgk25/jbigkit/)`.

Fig. 1. The most significant bit-plane of the image "peppers" before and after the reordering procedure.

tained with JBIG after palette reordering with Memon's and the modified Zeng's methods include a Gray code conversion. This is the default mode provided by the JBIG codec, and is an effective procedure for encoding natural images on a bit-plane basis. Images reordered according to the bit-plane approach are encoded without this code conversion (`-b` flag of the JBIG codec).

The results presented in Table 1 show that Memon's method provides the highest average compression improvement for the three coding standards addressed in this paper. The bit-plane reordering, the fastest amongst the three palette reordering methods, attains better results when used with JBIG and, for some images, provides the best compression results. This shows the effectiveness of the method when used with a bit-plane based encoder.

For performing the reordering of all images presented in Table 1, our implementation of Memon's method required 140.6 seconds, whereas mZeng required 3.8 seconds. The bit-plane reordering needed only 1.2 seconds. These results were obtained on a Pentium IV Mobile 2.0 GHz with 512 MB of memory. We only took into account the time spent on parts of the code directly involved with the reordering operation. These time measures allow us to conclude that bit-plane reordering is, in fact, the fastest method and, on the opposite side, we have Memon's method.

5. CONCLUSIONS

Palette reordering is a very effective approach for improving the compression of color-indexed images. We presented compression results provided by three state-of-the-art image coding standards, namely, lossless JPEG2000, JBIG and JPEG-LS, used after preprocessing the color-indexed images with three palette reordering methods: Memon, modified Zeng and a bit-plane based method described in this paper.

From the experimental results obtained, we conclude that Memon's method is the best one in terms of average compression performance, although it is the slowest one. For the three palette reordering methods presented in this paper, JBIG gives the best compression performance among all coding standards used in this work, showing its effectiveness on this type of images. Finally, we notice that the bit-plane based palette reordering method proposed is the fastest amongst all three, giving good results when used in association to JBIG. In fact, for some images, it provides the best compression result.

6. REFERENCES

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Table 1. Lossless compression results, in bits per pixel, obtained with JPEG-LS, JBIG and JPEG2000, after reordering the palette of the color-indexed images using Memon, mZeng and the bit-plane based palette reordering methods.

Images	#colors	JPEG-LS			JPEG2000			JBIG		
		Memon	mZeng	Bitp	Memon	mZeng	Bitp	Memon	mZeng	Bitp
pc	6	0.748	0.745	0.812	0.748	0.749	1.082	0.264	0.261	0.331
books	7	1.453	1.469	1.911	1.598	1.601	1.862	1.246	1.220	1.298
music	8	1.051	1.051	1.171	1.374	1.374	1.708	0.665	0.665	0.770
winaw	10	0.450	0.450	0.536	0.611	0.611	0.812	0.370	0.370	0.407
party8	12	0.321	0.318	0.336	0.411	0.413	0.571	0.162	0.167	0.180
netscape	32	1.745	1.752	2.113	2.382	2.390	2.900	1.752	1.792	1.873
sea_dusk	46	0.197	0.189	0.196	0.255	0.129	0.201	0.076	0.065	0.076
benjerry	48	1.133	1.137	1.323	1.745	1.769	2.207	1.108	1.169	1.086
gate	84	2.548	2.566	3.337	2.987	3.037	3.955	2.565	2.492	2.692
descent	122	2.817	2.854	3.603	3.499	3.424	4.530	2.705	2.561	2.595
sunset	204	2.407	2.307	2.735	3.424	3.263	4.048	2.060	2.058	2.425
yahoo	229	1.743	1.789	2.195	2.220	2.253	2.890	1.755	1.710	1.852
airplane	256	4.202	4.445	5.866	4.506	4.748	6.302	4.383	4.507	4.950
anemone	256	4.678	4.966	6.223	5.340	5.678	6.999	4.612	4.807	4.663
arial	256	5.890	6.183	6.905	6.144	6.512	7.273	5.705	5.857	5.580
baboon	256	6.272	6.496	7.029	6.498	6.697	7.221	6.287	6.442	6.037
bike3	256	4.034	4.154	5.072	4.720	4.847	5.888	3.724	3.894	4.047
boat	256	5.236	5.823	6.627	5.538	6.077	6.851	5.341	5.717	5.296
clegg	256	5.220	5.456	6.072	5.951	6.126	6.730	4.585	4.750	4.843
cwheel	256	2.724	2.878	4.284	3.068	3.243	5.025	2.099	2.129	2.805
fractal	256	5.763	5.828	6.612	5.974	6.038	6.872	5.681	5.700	5.425
frymire	256	3.259	3.376	3.916	4.093	4.217	4.994	2.403	2.523	2.649
ghouse	256	4.229	4.541	6.201	4.760	5.091	6.867	3.960	4.113	4.632
girl	256	5.107	5.255	6.392	5.357	5.545	6.644	4.916	5.019	4.878
house	256	4.467	4.854	5.390	4.820	5.139	5.658	4.640	4.917	4.793
lena	256	4.519	5.049	6.305	4.834	5.435	6.672	4.478	4.806	4.450
monarch	256	3.715	3.917	5.086	4.344	4.520	6.002	3.404	3.551	4.122
peppers	256	4.740	5.019	5.889	5.081	5.398	6.265	4.443	4.542	4.296
serrano	256	3.001	3.273	3.830	4.038	4.323	5.257	2.308	2.468	2.890
tulips	256	3.703	4.032	5.352	4.252	4.656	6.175	3.589	3.767	4.303
Average	–	2.982	3.122	3.744	3.377	3.520	4.321	2.600	2.691	2.803

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