IMPROVED REDUNDANCY REDUCTION FOR JPEG FILES

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ABSTRACT

In this paper several methods are presented that allow improved compression of JPEG image files. This is mainly achieved through segmented entropy coding in reference to the EOBs (End-of-Block) of the 8x8 DCT transformed macroblocks. All of the algorithms discussed here are implemented in the freely available JPEG compression software 'packJPG' [9].

Our approach reduces baseline JPEG image file sizes by an average of 15%, based on tests with the Kodak image set [1] and 800 randomly selected JPEG files. This is an improvement of about 5% over a recent proposal [2] for the JPEG standard.

1. INTRODUCTION

JPEG, which was developed by the Joint Photographics Experts Group and standardized in the year 1992, is at the present time the most widely used compressed image format. Practically all digital cameras rely on this format and the majority of images on the Internet are stored as JPEG files. Because of their already compressed nature, universal compression programs like ZIP, RAR or 7-ZIP can not reduce the size of JPEG compressed files any further. An image stored in the JPEG format can be converted to a superior format, like JPEG-2000. But, usually if an image is converted from a lossy compressed format to another lossy compressed format there is an additional (and unnecessary) loss of quality. Our aim was to provide higher lossless compression for JPEG files in a compatible manner.

A recent suggestion to further lossless compress a JPEG image file is the arithmetic coding technique proposed by the ITU and known as 'Q15 coder' [2]. With this method the size of a baseline JPEG file can be reduced by an average of 8%...10%.

In our approach, the JPEG file is first decompressed to quantized DCT coefficients. The coefficients are then rearranged to 64 subimages for each color component contained in the image. Each subimage contains all the coefficients of one 'subband' corresponding to the 2D DCT basis functions.

Figure 1 shows a part of the 8x8 DCT subbands (luminance component) of the well known ‘lena’ (512x512) image. 4x4 of the 8x8 subbands are shown of the lowest four frequencies in vertical and horizontal direction.

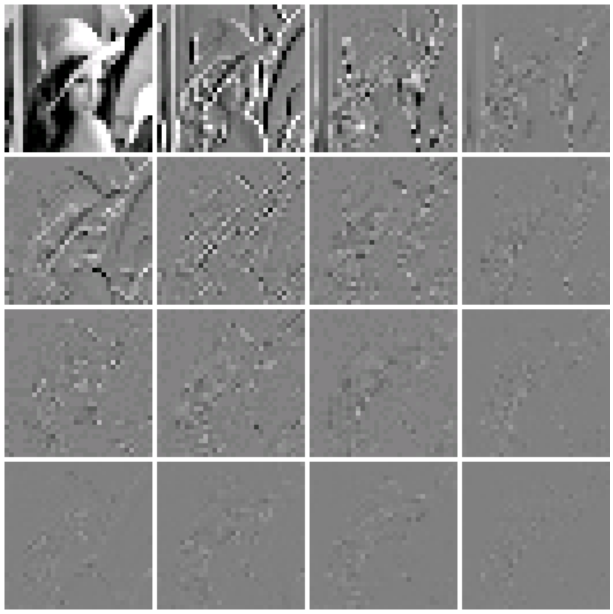

Figure 1: The upper left 4x4 of the luminance coefficient image of 'Lena'

Typically there are statistical dependencies between corresponding DCT coefficients of neighboring blocks. In baseline JPEG this redundancy is only utilized for the coefficients of the DC subband to some extent by using differential encoding.

The remainder of this document is structured as follows: Section 2 describes an improved prediction method for the DC subband, the Paeth predictor. Section 3 explains the concept of End-of-Block lists and their benefits. The improvement achieved by using a frequency dependent scanorder is demonstrated in Section 4. Section 5 explains the special entropy coding used in our approach. In Section 6 results are presented. Section 7 concludes the paper.

2. PAETH PREDICTOR

The grouped coefficients of the DC subband show a small version of the original image. Therefore the same decorrelation techniques used for grayscale images can be applied.

The Paeth predictor is described in the specification of the PNG compressed image format [3]. It is an 'intelligent' predictor that tries to choose the best possible direction for the prediction of each pixel. A simple linear function of the three neighboring pixels (left, above, above-left) is computed, then the pixel closest to the result is chosen as the prediction.

In our approach, the coefficients of the DC subband are coded using the Paeth predictor.

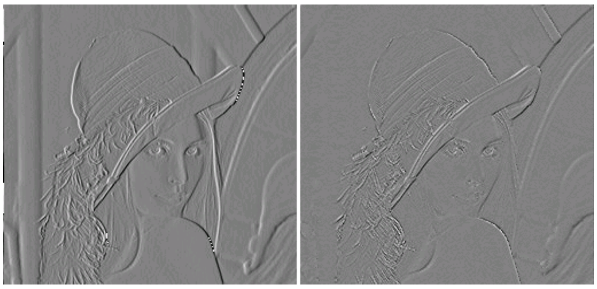

Figure 2: 'Lena' prediction error image using linear predictor (left) and paeth predictor (right). First order conditional entropy for the left image is 4.7 bit per pixel and 4.0 bit per pixel for the right image.

Figure 2 shows the improvements of the Paeth predictor over the simple linear predictor used in baseline JPEG.

3. EOB LISTS

In a macroblock of 64 coefficients, sorted in zig-zag order, the End-Of-Block (EOB) is defined as the position after the last nonzero coefficient. All the EOBs of each macroblock from one color component grouped together form the EOB list for this color component.

In usual quality settings of JPEG compression most coefficients are quantized to zero and in fact most zero quantized coefficients occur at the end of the zig-zag scanorder. So the EOBs can be used to effectively group and encode those last zeroes. This is also done in a similar way in baseline JPEG without EOB lists but rather with special EOB symbols.

In this approach the EOB lists are used for an additional purpose. It can be safely assumed that the later the EOB occurs in a macroblock, the greater the number of high frequency structures contained in it. Macroblocks with high EOBs have other statistical properties than those with low EOBs.

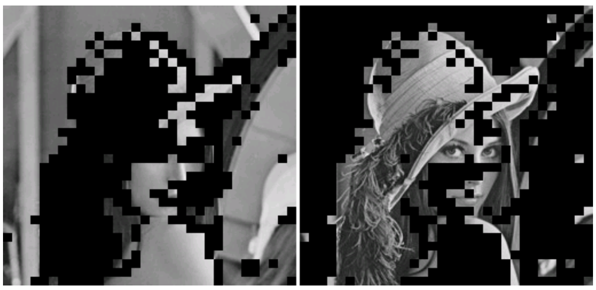

Figure 3: Areas with low (left) and high (right) EOBs in 'Lena'; others are masked out

This is demonstrated by figure 3. In the left picture all 8x8 blocks with high EOBs are marked in black. In the right picture all blocks with low EOBs are marked black.

In our approach 8x8 blocks are grouped according to their EOBs. Each group of blocks is coded independent of the other groups. This can be done not only with 2 levels but with even more. The optimum number of levels varies from picture to picture. It is dependent on the size of the picture. Level thresholds are calculated through linear quantiles of the EOB list, for example 25%, 50%, 75%, 100% for four levels.

For this to work, EOB lists have to be stored inside the compressed files, which increases the data rate. Our tests have shown that, instead of storing the actual EOBs, there are overall better results if, for each EOB, only a threshold value is stored.

4. OPTIMIZED SCANORDERS

The coefficients are coded per subband, coefficient for coefficient, using a first order statistical model with the immediate predecessor as context. Compression is further improved by using frequency dependent scanorders in the spatial domain. Figure 4 shows, for each subband of the frequency spectrum, the corresponding scanorder used in our approach.

DC	V	V	V	V	V	V	V
H	M	V	V	V	V	V	V
H	H	M	V	V	V	V	V
H	H	H	M	V	V	V	V
H	H	H	H	M	V	V	V
H	H	H	H	H	M	V	V
H	H	H	H	H	H	M	V
H	H	H	H	H	H	H	M

Figure 4: Scanorders used for each subband in our approach: horizontal, vertical and meander scans. For the DC subband meander scans are used.

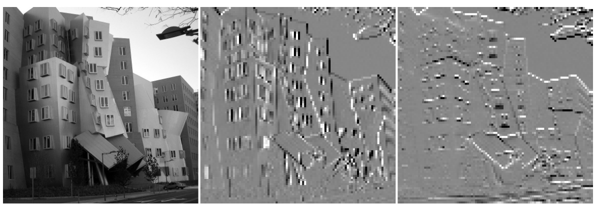

Figure 5: The left image is the original image 'DSCN5081' [4], the subband at (1,0) (middle image) is mainly defined by vertical edges, the subband at (0,1) (right image) is mainly defined by horizontal edges. This can be utilized to determine more efficient scanorders within the subbands..

Instead of using a simple line per line scanorder, a horizontal scanorder is used only for subbands in the lower right of the frequency spectrum, as these are mainly defined by horizontal edges. For subbands in the upper right of the frequency spectrum a vertical scanorder is used, as these are mainly defined by vertical edges. This is demonstrated in figure 5.

For subbands in the middle diagonal of the frequency spectrum, a special meander scan consisting of several Hilbert curves is used. Our tests have shown that, for these subbands, this always leads to better overall compression than would be possible with purely horizontal or vertical scanorders.

5. ENTROPY CODING

In this approach arithmetic coding with different statistical models for different types of data is used. Different statistical models for each data type were tested and those that gave the best results were kept.

The JPEG file header, which is also needed for fully lossless compression, is encoded using a simple first order statistical model.

EOB lists are encoded as thresholds using a two dimensional first order statistical model. For each EOB value, the EOB values of the blocks left and above are used as context.

DCT coefficients are encoded separately according to signs, absolute values and categories. This scheme is explained as follows.

In most cases, signs of DCT coefficients cannot be compressed much below 1 bit per coefficient unequal zero. Using optimized scanorders and first order statistical modeling their compressed size can usually be reduced below 1 bit per symbol, but not by much.

The remaining absolute values of the DCT coefficients are encoded using a scheme very similar to the VLI (Variable Length Integer) scheme used in baseline JPEG entropy coding. Absolute values are first categorized, then further specified. The categories are encoded using optimized scanorders and a simple first order statistical model. The immediate predecessors category is used as context. The further specification of the coefficient is encoded using a more complex first order statistical model with the category as context. The parameters of this model were derived by analyzing the coefficient distributions of several hundred empirically selected JPEG files of JPEG quality setting 100%. As coefficient distributions change with different JPEG quality settings, the parameters are scaled to fit these. Tests have shown that this model works well for natural, photographic images from various sources.

For this to give optimal results, categories have to be chosen carefully. If a category has a large range, more data is needed to encode the further specification of the coefficient. Values that occur often have to be in a small range category, those that occur rarely have to be in a big range category. This is simple, because DCT coefficients contained in one subband usually follow the Laplace distribution. An exponential distribution of categories is used, beginning with small range categories holding the frequently occurring small absolute values and ending with big range categories for the rarely occurring big absolute values.

6. RESULTS

For the first experiment the approach was tested on the Kodak image set [1]. Figure 6 shows compression results for all 24 images. Compression ratios were determined in reference to the file sizes of the baseline JPEG images with standard huffman tables and 4:2:0 subsampling in JPEG quality setting 90%. All compressed files can be restored to the original JPEG files without any loss.

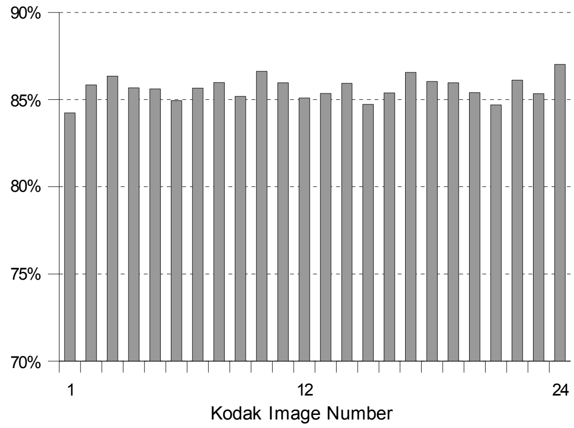

Figure 6: Further compression of the Kodak image set in JPEG quality setting 90%. The best result is achieved for image no 1.

Similar results were reported by http://www.maximumcompression.com and http://www.compression.ca after testing a beta release of the program 'packJPG'.

The second experiment demonstrates the dependency of our approach on the quality of the original JPEG image. 'Lena' was encoded using standard baseline JPEG, then compressed further using our algorithm, progressive optimized JPEG and the Q15 coder [2]. This was done for each quality setting from 1% to 100%. Results are shown in figure 7.

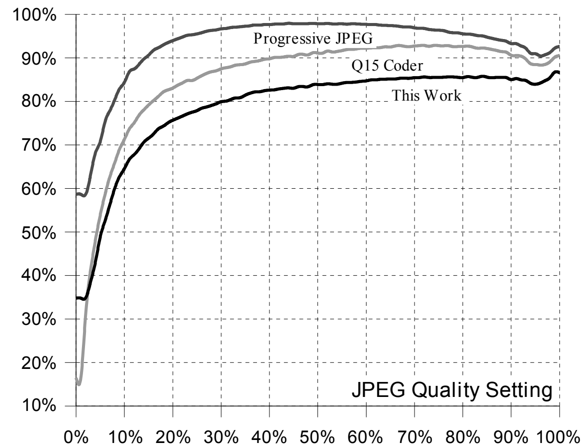

Figure 7: 'Lena' compression ratios for various JPEG quality settings. In quality settings from 70% - 95% our approach improves compression by 14% over baseline JPEG.

Figure 8 demonstrates dependencies on the quality of the original JPEG image using a rate distortion plot. JPEG-2000, our approach and baseline JPEG are compared. For encoding of JPEG-2000 images the 'JPEG-2000 JP2 File Format' (JasPer) codec of XnView 1.91 [5] was used. JPEG files were encoded with 'cjpeg' [6] using option '-dct float'.

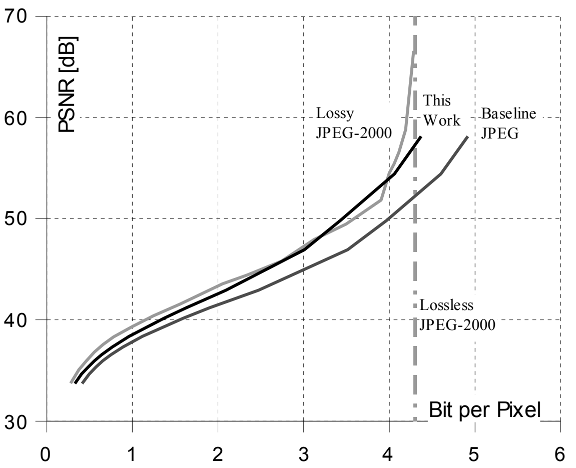

Figure 8: Rate distortion plot for baseline JPEG, JPEG-2000 and our approach for the luminance component of 'Lena'.

A fourth experiment was performed to compare our approach to other forms of JPEG compression. The full Kodak image set [1] was compressed using various types of JPEG compression and our approach, each in JPEG quality setting 90%. Figure 9 compares each algorithm by average compression ratio in reference to the sizes of standard baseline compressed JPEG files with 4:2:0 subsampling.

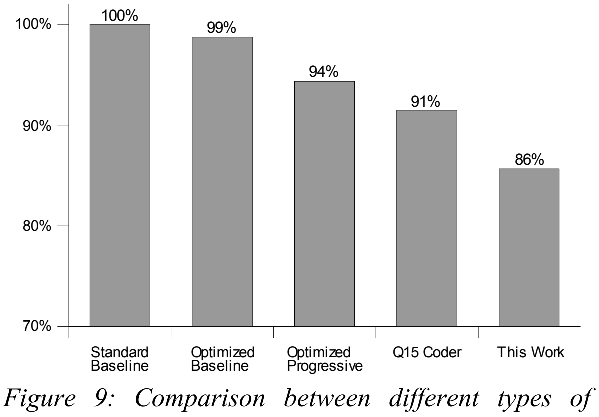

Figure 9: Comparison between different types of JPEG compression and our approach using the Kodak image set. Our approach gives 5% more compression than the Q15 coder proposal [2].

We also compared our results to the ones reported by Bauermann and Steinbach in [7]. 16 of the 24 Kodak images [1] were compressed using the approach reported in [7]. The average additional compression was 5%, while 'packJPG' achieved 15%.

Using a set of 200 files randomly selected from the Internet, the average size reduction was 14% in [7], while our approach yields 17%.

Compared to 'PAQ8L' [8], a freely available state-of-the-art compression program, our compression is about 1% less for the Kodak image set [1] in JPEG quality 90%, but compression time is 10 times as fast.

Recent improvements of 'PAQ8' as well as 'packJPG', which are not covered in this paper, increase the compression ratio by several percent.

7. CONCLUSIONS

This paper presented several ways to improve redundancy reduction of JPEG files, mainly achieved through segmented entropy coding in reference to EOBs. Arithmetic entropy coding is used in conjunction with specially selected and customized statistical models for different types of data. Typically baseline JPEG files can be compressed by an additional 15% on average using this approach. Its rate-distortion-performance is close to JPEG-2000.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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