 

# Introducing a Decorrelated Color Space in the Lossy Compression of Pre-press Applications

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## Abstract

When compressing color images in pre-press applications one has to deal with four different color channels. Usually there exists a high correlation between the different colors in natural images. In the type of images that will be dealt with in this paper, this correlation is even higher because of the addition of a fourth color component, black, due to various technical reasons. This paper shows that a significant gain in data reduction can be achieved by taking this color redundancy into account. Before performing a lossy block-based compression technique like JPEG, a singular value decomposition (SVD) is performed on the data. Therefore the image is divided into blocks, that usually have a different size than those used in the JPEG step, and the SVD is applied locally to decorrelate the colors in the spatial domain.

## 1. Introduction

The storage of electronic images in the pre-press industry is becoming a major concern. One solution might be to use compression technology in order to enlarge the storage capacity and enhance the transmission speed of the image data over a network.

In the printing industry, one usually works with color images that consist of four color components, i.e. cyan, magenta, yellow and black (CMYK). The reason is that for printing purposes one needs subtractive colors, because in the printing process the incident light is being partly absorbed by the various inks on top of each other. Cyan, magenta and yellow are used because they filter out respectively red, green and blue. Because of imperfections in the absorption curves of the three process inks, because the paper can absorb only a limited amount of ink and because black ink covers more, black is added as the fourth color component. Furthermore, black is much cheaper than the color inks and it is needed anyway, for instance to print text. The addition of this fourth component introduces a higher redundancy between the different color components.

In pre-press applications 32 bits are used to represent the color information per pixel (8 bits per color channel). Because the digital representation allows to reproduce the color tones in an almost continuous way, these images are called *contone* images. Due to the large amount of image data, and because lossless algorithms do not yield enough data reduction, a lossy compression technique might be considered.

The current standard in lossy compression is JPEG [1]. In the current JPEG implementations, the four color components (CMYK) are treated independently from each other, or in some algorithms the CMYK color space is transformed in a luminance-chrominance space like the YUV space where the two chrominance components U and V are subsampled. This last method is not prefered however in the case of high quality pre-press images. In neither of the ways stated above, the correlation between the four color components is taken into account, so there remains a high redundancy that is not exploited efficiently.

The concept of taking the tonal redundancy into account also has been investigated by Said and Pearlman [2]. They use a combination of the Karhunen-Loève transform and their wavelet based SPIHT coder but only evaluated it on RGB images and performed the KLT on the entire image, what makes it not so efficient, especially not for high resolution pre-press images.

The paper is organized as follows. In section 2, we propose our technique where the image data is first decorrelated by means of a singular value decomposition in a block-based manner and then compressed using DCT-based JPEG. In section 3, we apply the proposed technique on some typical high quality pre-press images. Section 4 concludes with a summary.

## 2. Using a block-based decorrelation of the color space

Transforming the four dimensional CMYK color space to a three dimensional color space, like YUV in some JPEG applications, is not prefered in pre-press applications since

 

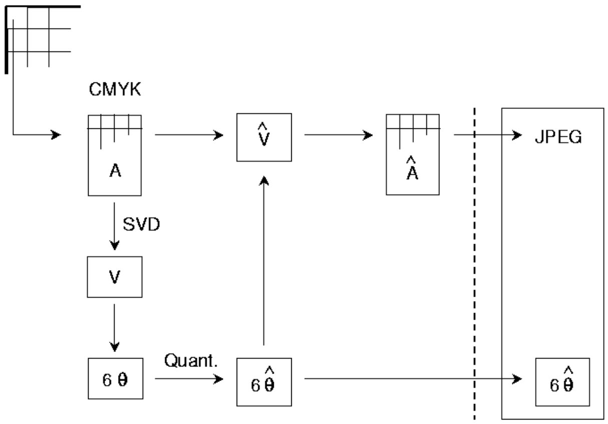


*Figure 1*: *Compression step of the proposed technique.*

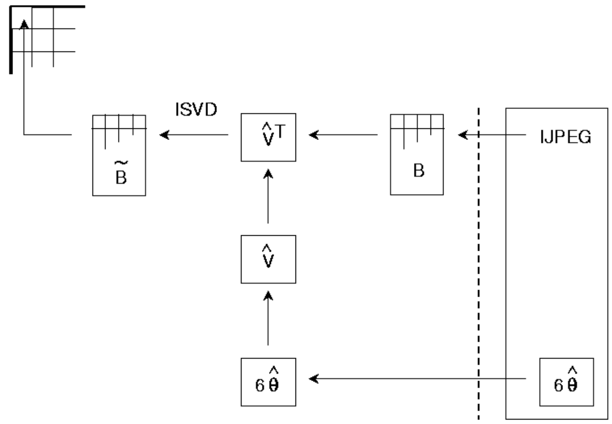


*Figure 2*: *Decompression step of the proposed technique.*

it makes the inverse transformation irreversible. We therefore want to transform our data to a new four dimensional space that is more suitable for data reduction. According to information theory the resulting space will be so that the different components are uncorrelated. In such a space the total image energy is spread non-uniformly over the different color channels. This usually means that only one component will have a large amplitude. Practically this component needs some more bits to be coded as accurately as with a non-optimal space but the other components can be coded with a lot less bits. Therefore the overall compression ratio will increase.

In order to be sure that the technique works efficiently, it is important to apply it on an image area in which the color contents doesn't vary to much. In this way the principal axis of the new space will be along that of the most dominant color and the other components will be small and easier to code with less bits. An easy way to meet with this condition is to divide the image in blocks. Note that we will work with square blocks of m×m pixels in what follows.

Suppose we have a ($\mathrm{m}^2 \times 4$) color image block $A$ built up like:

$$A = \begin{pmatrix} a_{1,\mathrm{C}} & a_{1,\mathrm{M}} & a_{1,\mathrm{Y}} & a_{1,\mathrm{K}} \\ \vdots & \vdots & \vdots & \vdots \\ a_{\mathrm{m}^2,\mathrm{C}} & a_{\mathrm{m}^2,\mathrm{M}} & a_{\mathrm{m}^2,\mathrm{Y}} & a_{\mathrm{m}^2,\mathrm{K}} \end{pmatrix} \qquad (1)$$

In $A$ a base $E_{\mathrm{CMYK}}$ is defined to represent the four correlated color components. We now try to find a transformation matrix $V$ so that $E' = V.E$. In the new base $E'$ the colors are correlated minimally. This transformation can be achieved by performing a *singular value decomposition* (SVD)[3] on $A$:

$$A = USV^T = \sum_{i=1}^{4} \sqrt{\sigma_i}\mathbf{u_i}\mathbf{v_i^T} \qquad (2)$$

with $U \in \mathbb{R}^{\mathrm{m}^2\times 4}$ and $S \in \mathbb{R}^{4\times 4}$ a diagonal matrix with the diagonal elements $\sqrt{\sigma_i}$ $(i = 1, \ldots, 4)$ representing the singular values of $A$. $\sigma_i$ are the eigenvalues of $AA^T$ or $A^TA$. $V \in \mathbb{R}^{4\times 4}$ and is the orthonormal transformation matrix, that satifies $VV^T = V^TV = 1$ and det($V$)=1. The column vectors $\mathbf{u_i}$ and $\mathbf{v_i}$ of resp. $U$ and $V$ also satisfy:

$$A\mathbf{v_i} = \sqrt{\sigma_\mathbf{i}}\mathbf{u_i} \qquad (3)$$

and

$$A^T\mathbf{u_i} = \sqrt{\sigma_\mathbf{i}}\mathbf{v_i} \qquad (4)$$

In general, any two dimensional transform decomposes the image into a weighted sum of basis images. The weight coefficients are called the transform coefficients and the transformation is completely characterized by the set of basis images. In the case of the SVD, the basis functions are $\mathbf{u_i}\mathbf{v_i^T}$ and the transform coefficients are $\sqrt{\sigma_i}$ [4].

In the application of this paper, we are mostly interested in the transformation matrix $V$. From the unitary matrix $V$ it's always possible to decompose it into the product of rotation matrices. For the four dimensional matrix $V$ this results in six rotation angles $\theta_i$ $(i = 1 \ldots, 6)$. It is necessary to store these angles in order to obtain the reconstructed image data in the decompression step. In our method we quantize the angles to 1 byte. This results in a set of new new angles $\hat{\theta}_i$ from which a new, slightly different, transformation matrix $\hat{V}$ can be calculated. In order to minimize the loss at this moment the color data corresponding to the quantized transformation matrix $\hat{V}$ is calculated as:

$$\hat{A} = A\hat{V} \qquad (5)$$

*Table 1*: *Sub-optimal block size for the proposed technique applied on some 32 bpp images*

| image | size | sub-optimal block size |
|---|---|---|
| cafe | 2048 × 2056 | 32 |
| xfld_fogra | 780 × 1002 | 16 |
| scid0 | 2048 × 2560 | 32 |
| musicians | 1853 × 2103 | 32 |

An important property of $\hat{V}$ is that it is also a unitary matrix. On the transformed color components $E_{\hat{C}_1\hat{C}_2\hat{C}_3\hat{C}_4}$ of $\hat{A}$ the JPEG algorithm is performed. It is useful to remark that the quantization was done both by using a traditional quantization matrix and a flat matrix, i.e. all quantization coefficients are chosen equal. In the decompression step the JPEG data blocks are decompressed and the rotation angles are dequantized. By performing the inverse SVD the color components are reconstructed in the original base. The outline of the compression step can be seen from figure 1. The decompression step is illustrated in figure 2. It is quite similar to the compression step, although it is more simple, since the correct rotation angles $\hat{\theta}_i$ are known. The reconstructed color data $\tilde{B}$ can be calculated from the decompressed JPEG data B by

$$\tilde{B} = B\hat{V}^{-1} \tag{6}$$

and since $\hat{V}$ is orthogonal, $\hat{V}^{-1} = \hat{V}^T$ so

$$\tilde{B} = B\hat{V}^T \tag{7}$$

## 3. Experimental results

As to the quality of the reconstructed images, the peak-signal-to-noise-ratio (PSNR)

$$\text{PSNR} = 10\log_{10}\frac{255^2}{\text{MSE}} \tag{8}$$

is used as the performance measure, where the MSE denotes the mean square error over the entire image. It is calculated as:

$$\text{MSE} = \frac{1}{4}\sum_{i\in(C,M,Y,K)}\text{MSE}_i \tag{9}$$

with

$$\text{MSE}_i = \frac{1}{MN}\sum_{x,y}\left[f_i(x,y) - \tilde{f}_i(x,y)\right]^2 \tag{10}$$

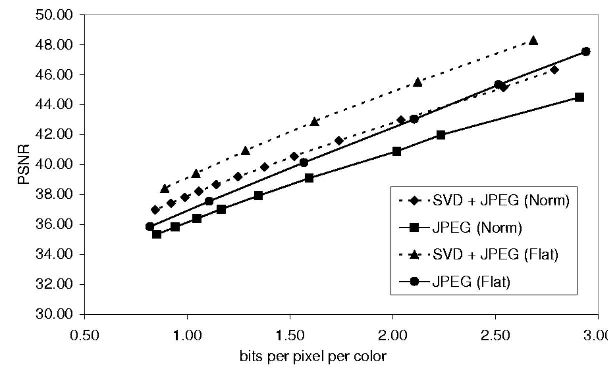


*Figure 3*: *Rate-distortion curve for the musicians image.(Norm) denotes the quantization matrix from eqn 11 was used, (Flat) denotes all elements in the quantization matrix are chosen equal.*

where $f_i(x,y)$ represents the original color component image, $\tilde{f}_i(x,y)$ is the reconstruction and $MN$ is the number of pixels in the $M \times N$ image. All four of the SVD principal components were used when the image was processed by the DCT technique. The only quantization step in the algorithm occurs in the quantization process in JPEG [5].

The first quantization method is based on the $Q$-table that is used in most popular JPEG compressors, i.e.

$$Q_{u,v} = \begin{pmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{pmatrix} \tag{11}$$

It is well known that this $Q$-table was empirically developed taking into account the visual perception of a human. The second scheme we used is the very simple flat matrix quantization. In this case, all quantization coefficients are chosen equal, i.e. all coefficients are quantized as coarsely.

At first an investigation was done to find the sub-optimal block size that should be used in performing the SVD on the spatial color data. In our test, some representative prepress test images were used, i.e. musicians, cafe, xfld_fogra and scid0. The investigated block sizes are 8×8, 16×16, 32×32 and 64×64. As can be seen from table 1, in most cases a sub-optimal block size of 32×32 was found. Only in the case of the xfld_fogra image it seemed 16×16 was slightly better, although the difference was insignificant.

From the rate-distortion curve in figure 3, it follows that we get a significant increase in the peak-signal-to-noise-ratio for the same bitrate. Furthermore it seems that an ad-

 

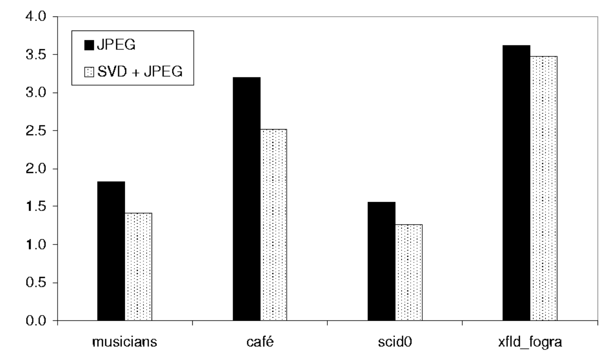


*Figure 4*: *Comparison of JPEG and proposed technique on four test images for PSNR = 40 and using the quantization matrix from eqn 11.*

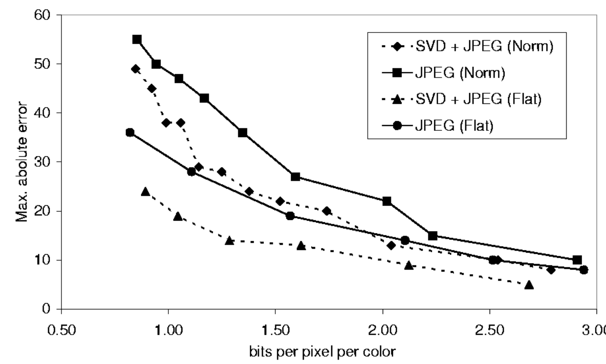


*Figure 5*: *Maximum absolute error versus the bitrate for the musicians image.*

ditional gain is achieved by using the very simple flat matrix in the quantization procedure. An explanation for this behaviour is that when the data reduction is not too high, the quantization errors will be small in every case. So there is no reason why a low frequency coefficient should be quantized more or less than a high frequency coefficient. In the specified bitrate region, compression ratios between 3 and 8, the visibility of the artifacts is very small, so one can doubt the necessity to use a sofisticated quantization matrix in this case. Part of this phenomenon is also due to the use of the PSNR, or MSE, that is calculated as the image distortion measure. It is widely accepted that the human eye doesn't interpret distortion in a "PSNR" way. Nevertheless it is a good indicator in our region of interest.

In figure 4 the achieved bitrate is shown for three other images as well at a PSNR of 40 (MSE = 6.5). In all cases the proposed technique shows a significant improve in data reduction, except for the hard to compress xfld_fogra image. For a PSNR of 40 and using the conventional quantization matrix, gains are in the range of about 20% in bitrate.

Because of the limited usability of the PSNR as a distortion measure, another high important error measure is often used in the pre-press industry, i.e. the maximum absolute error. From figure 5 a decrease in maximum absolute error is noticed by using the proposed technique in comparison with JPEG. The best results are achieved using a flat quantization matrix. For instance, for a maximum absolute error of 20, one gets a gain of 33% in bitrate.

## 4. Conclusion

In this paper we have considered a new algorithm in the lossy compression of high resolution pre-press images. The novelty of the method lies in exploiting the tonal redundancy that exists between the different color channels in natural *contone* images, especially in four color component pre-press images. The proposed algorithm divides the image into blocks. The color components are then locally decorrelated using a singular value decomposition (SVD). Of the new "colors", in general only one will be large in intensity, while the others are small and can be coded with less bits. On the different color channels, the lossy JPEG algorithm is applied.

In terms of image quality and data rate we may conclude that the combination of SVD and JPEG for image coding has some advantages in future applications.

## 5. Acknowlegdements

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