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OPTIMIZING THE COLOR SPACE CONVERSION FOR IMAGE COMPRESSION

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Abstract The performance of an image compression scheme depends on the color space being used. The luminance – chrominance color spaces are widely used, because they enable the speculation of the human eye color sensitivity. Some of the existing luminance – chrominance color spaces were developed for analog television, and others for digital applications. This paper presents a method for optimizing the color space transformation, for image compression.

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1. Luminance – Chrominance color spaces

The best color spaces for image compression are the *Luminance – Chrominance* (LC) color spaces. Due to the eye sensitivity the chrominances can be represented at lower resolutions than the luminance signal, without inducing perceptible distortions. The conversion from the RGB space to a LC space is defined by the next linear transform:

$$\begin{bmatrix} Y \\ C' \\ C'' \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ cr_1 & cg_1 & cb_1 \\ cr_2 & cg_2 & cb_2 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

where Y is the luminance signal and C' and C'' are the two chrominances. The first row of the matrix is fixed for all the LC spaces, and it was deduced experimentally. The second and the third row coefficients express the differences between all the known LC color spaces [3][4][6].

The grey pixels have equal levels of R, G and B. For those pixels, both the chrominances should be 0. In order for this condition to be satisfied, the sums of the coefficients in the second and third row of the transform matrix presented in (1) must be 0. Thus, relation (1) can be rewritten:

$$\begin{bmatrix} Y \\ C' \\ C'' \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ cr_1 & cg_1 & -cr_1 - cg_1 \\ cr_2 & cg_2 & -cr_2 - cg_2 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = [A] \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

The inverse transform from the $YC'C''$ space to the RGB space is given by:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = [A]^{-1} \begin{bmatrix} Y \\ C' \\ C'' \end{bmatrix} = \begin{bmatrix} 1 & c'_1 & c''_1 \\ 1 & c'_2 & c''_2 \\ 1 & c'_3 & c''_3 \end{bmatrix} \begin{bmatrix} Y \\ C' \\ C'' \end{bmatrix} \quad (3)$$

The last step was possible because of the particular form of matrix A. The first row sum is 1, and the second and third rows sums are 0. This implies that the first column coefficients of $[A]^{-1}$ are all equal to 1. Relation (3) indicates that for the pixels that have no color (C' and C'' are 0), the R, G and B components given by the inverse transform are all equal to Y, and this is true regardless of the cr_1, cr_2, cg_1 and cg_2 coefficients values.

2. The properties of an ideal LC color space

An ideal LC color space for image compression would have orthogonal axes Y, C' and C''. This would reduce the redundancy between the image components. A simple calculation shows that this is not possible, because of the special form of the transform matrix presented in (2). At least one of the chrominances (for example C') can be chosen in such a way that Y and C' are orthogonal.

The redundancy in the image components can be reduced with prediction techniques. One of the most important characteristics of a color space for image compression is the capability to concentrate the signal energy in the low frequency subbands. Because the low subbands contain fewer coefficients, they can be encoded with high efficiency. The wavelet transform was considered, because it is one of the best transforms for image compression [1][2][5].

The total number of coefficients nc in subband n is:

$$nc = 3 \cdot 2^{2(n-1)} \quad , n \geq 1 \tag{4}$$

The signal energies for a subband with wavelet coefficients c_{ij} is given by the next relations:

$$ve(n) = \sum_{i=0}^{h-1} \sum_{j=h}^{2h-1} c_{ij}^{\;2} \; , \qquad he(n) = \sum_{i=h}^{2h-1} \sum_{j=0}^{h-1} c_{ij}^{\;2} \tag{5}$$

$$de(n) = \sum_{i=h}^{2h-1} \sum_{j=h}^{2h-1} c_{ij}^{\;2} \; , \; h = 2^{(n-1)}, \; n \geq 1 \; ,$$

where n is the subband number and ve, he and de are the vertical, horizontal and diagonal subband energies.

The total signal energy of subband n is:

$$E(n) = \begin{cases} he(n) + ve(n) + de(n) & , n \geq 1 \\ c_{00}^{\;2} & , n = 0 \end{cases} \; , \tag{6}$$

where c_{00} is the overall average (the 0 subband), and usually has the highest energy of all the other subbands.

3. Choosing the chrominance axes

Because it has no solution, the orthogonality requirement is dropped for the moment. This paragraph focuses on the signal subband energies. All the possible chrominance axes for a LC color space were defined in (2). In order to help choosing the best ones, a computer program was built, for performing the decomposition of an image for all the possible values of the cr and cg coefficients in the (-1, 1) interval (with a reasonable step). For each of the decompositions, the wavelet transform is computed, and the subband energies are evaluated. The output of the program is the *High Frequency subbands relative Energy* (HFSE) defined in (7), for each decomposition.

$$HFSE = 100\sum_{n=4}^{9} E(n) / \sum_{n=0}^{9} E(n) \qquad (7)$$

This process is presented in the next figure.

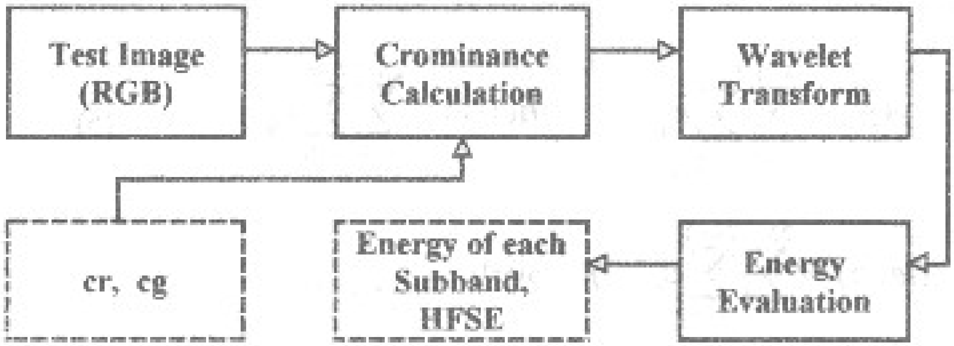

Figure 1

The test images dimensions were 512 x 512, so the maximum number of subbands (depending on the Wavelet Transform) is 9. The first three subbands and the overall average have together 64 coefficients, thus they can be encoded with little costs and are ignored in the analysis.

The program has the task of showing which of the possible LC color space axes have the capability to concentrate the image energy in the low frequency subbands. Figure *3a* and *3b* present the results of the program for two different images. The conclusion can be easily drawn: there is no LC color space that performs best for all the images. What is good for some images can be bad for others, depending on the color content and the spatial frequencies of different colors.

Figure 2 contains a top – view of the surface generated with the program data for a different image, and the position of the well – known color spaces coefficients *I* and *Q* of *NTSC*, and *Cr* and *Cb* of *YCrCb*.

The thick line indicates the *cr*, *cg* coefficient sets for which the chrominance and the luminance axes are orthogonal.

The four coefficients cr_1, cr_2, cg_1 and cg_2 can be chosen from the areas of low HFSE. If it is possible, one of the chrominance axes should be orthogonal on the luminance axis. The second chrominance must be chosen in such a way that the inverse transform would have small coefficients. For example, if $cr_1 = 0.5$, $cr_2 = 0.3$, $cg_1 = -0.2$ and $cg_2 = -0.7$, the following transform matrices are obtained:

$$[A]=\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.5 & -0.2 & -0.3 \\ 0.3 & 0.4 & -0.7 \end{bmatrix},\ [A]^{-1}=\begin{bmatrix} 1 & 1.756 & -0.590 \\ 1 & -0.937 & 0.564 \\ 1 & 0.217 & -1.3591 \end{bmatrix} \quad (8)$$

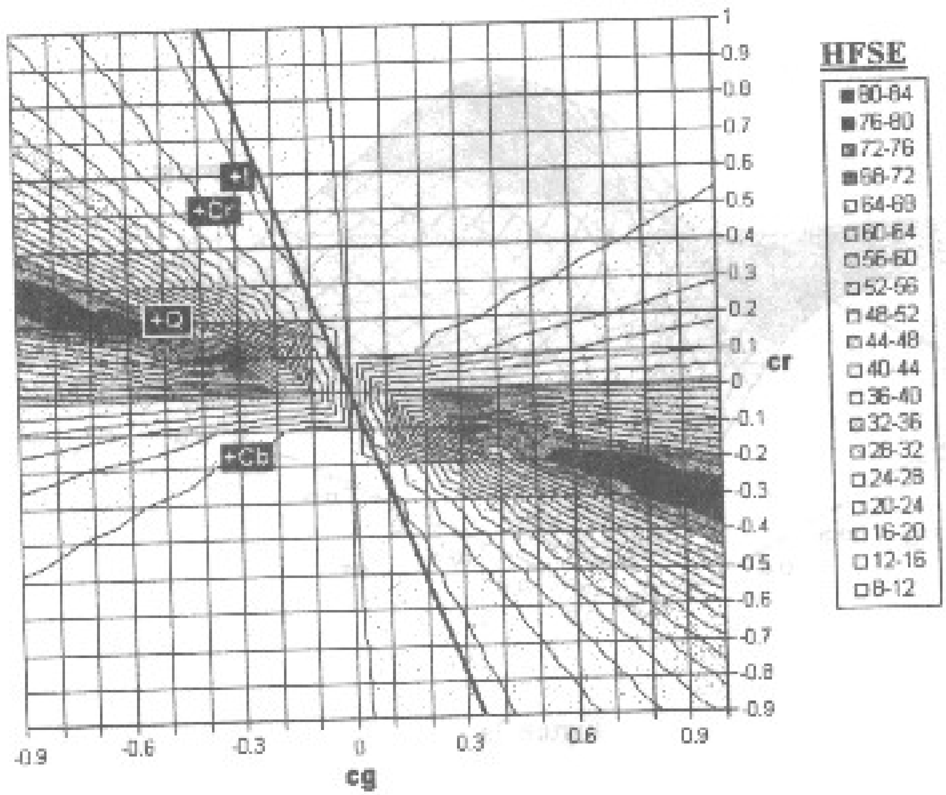

Figure 2

This type of analysis is not possible for real time applications. The encoding process is more difficult than decoding process. This asymmetry is acceptable if the images are encoded once, and then they are distributed to many consumers. The encoder must include in the data stream the color space specifications. It is not necessary for the encoder to perform the complete analysis, the good areas in the HFSE surface can be deduced with a few measuring points.

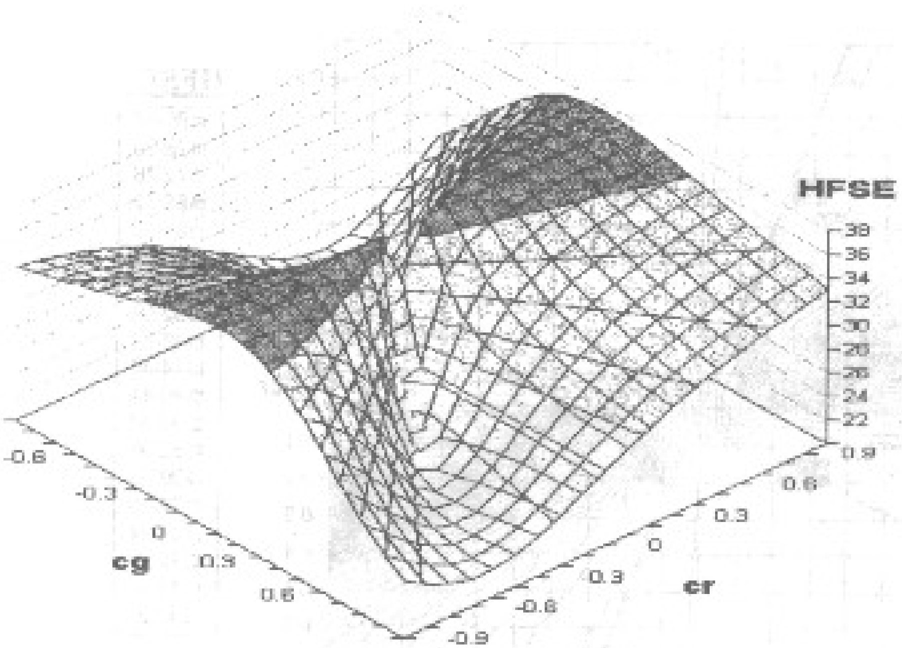

Figure 3a

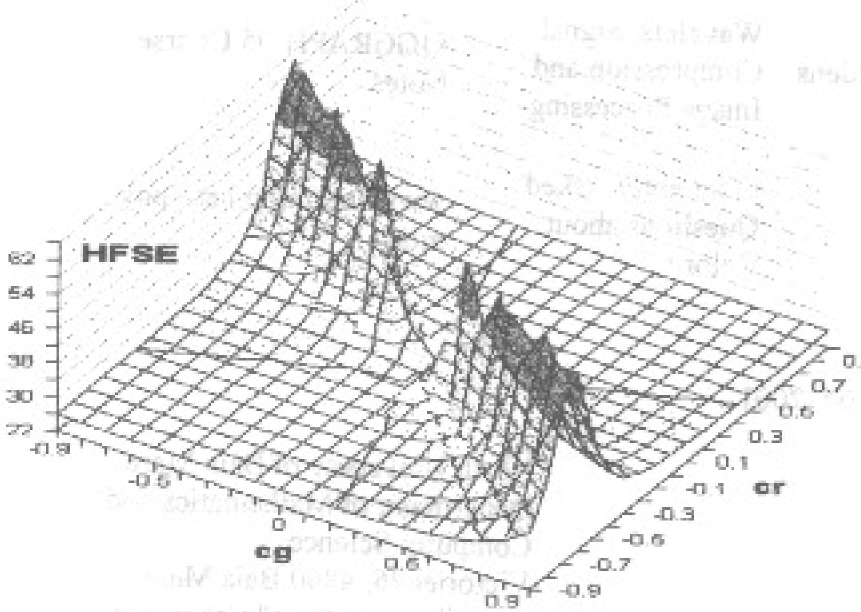

Figure 3b

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